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TECHNICAL PROBLEMS IN THE CONSTRUCTION OF RADIO VALVES

by TH. P. TROMP.

621.385

In this article several episodes in the history of the development of radio valves are discussed, particularly those concerned with the form of the valve. It is shown how the technical problem of whether glass or metal is the more suitable material for the bulb of the valve led to a complete revision of valve construction. The result is that radio valves can now be made either of glass or metal which satisfy all the requirements made by ordinary sets for the broadcasting region. The Philips key valves in glass or metal are finally discussed in detail. The conclusion is drawn that the difference in properties for the broadcasting region is so slight that neither of the two models is essentially preferable to the other. In the region of metre waves and shorter, however, the all-glass valves exhibit increasing advantages with decreasing wave length.

Introduction

The development which is observed in the form of every technical product, be it an electrometer, a lamp or an amplifier valve, is in general directed by two factors: first an ever-increasing insight into the physical laws which determine the function of a product, and second the problems and possibilities of manufacture. It may in general be said that for products which are manufactured only in small quantities the first factor is the more important, while in mass production the second factor also comes into prominence.

The question of which of the two above-mentioned factors determines the technical development also depends upon the nature of the product. If one considers a radio valve it may be said that the technical development of its electrode system is directed by a steadily increasing insight into the physical phenomena which determine its function. The external form of the radio valve, however, is quite a different question. As far as the function of the valve is concerned, the envelope, aside from providing contact in the socket, serves only to maintain a vacuum around the electrodes. From this point of view the external form of a radio valve would logically be a container which encloses the electrode system as closely as possible and through which mutually insulated connections are led. These connections would preferably be chosen in the form of short, straight wires, strong enough to be used as contact pins and far enough apart to cause no

undesired couplings between the various electrodes.

In this article we shall give several details from the history of the development of radio valves which have indeed finally led to constructions of the simple character described ¹⁾. The fact that this has occurred only after many years may not be ascribed to a lack of insight, but only to the difficulties which occur in the manufacture of a vacuum-tight container with sealed-in connections.

Historical survey

It would lead us too far if, in this article, we were to go into all the problems which are here encountered. It may be stated simply that the problem of the manufacture of a vacuum bulb with leads had previously reached an almost perfect solution in lamp manufacture, in the form of the so-called "pinch", so that it was obvious that this principle of construction could also be used for radio valves. The valves with pinch construction consist entirely of glass and are provided with a base with contact pins. The connecting wires to the electrodes must be soldered into these pins which are moulded or pressed in.

Although this construction by no means satisfies the above-mentioned requirement of smallest possible dimensions, and although the use of a base with pins to which leads must be soldered meant an undesired complication, this construction was

¹⁾ See Philips techn. Rev. 4, 162, 1939.

able to maintain its supremacy until the use of new materials for the envelope of the valve introduced a complete change in the form.

In 1935 in America metal radio valves appeared on the market (G.E.Co. and R.C.A.)²⁾. Relatively soon after this, metal valves also appeared to a limited extent in some European countries. Philips manufactured a large number of such valves for European and overseas markets.

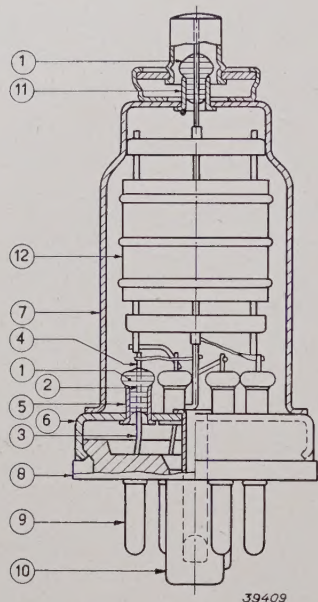


Fig. 1. Radio valve with metal envelope which appeared on the market in America in 1935.

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|--------------------------------|-------------------------|
| 1. Glass bead, | 7. Metal bulb, |
| 2. Molybdenum lead, | 8. Bakelite base, |
| 3. Nickel or copper connector, | 9. Hollow contact pin, |
| 4. Nickel support wire, | 10. Bakelite spigot, |
| 5. "Fernico" eyelet, | 11. Eyelet of top lead, |
| 6. Metal header, | 12. Electrode system. |

The first metal construction consisted of a fairly complicated arrangement, of which *fig. 1* illustrates a cross section. Briefly it is as follows. The "header" of the valve consists of a horizontal metal plate with a vertical cylindrical edge. In this header a number of holes are punched in which "Fernico" eyelets are welded. "Fernico" is an iron-nickel-cobalt alloy which can easily be welded to hard glass with a comparatively low coefficient of expansion³⁾ — about $50 \times 10^{-7}/^{\circ}\text{C}$. After welding, the eyelets are soldered with copper in order to obtain an absolutely reliable vacuum-tight joint. There is also

²⁾ We do not consider here constructions in which the bulb serves not only as envelope but at the same time forms a part of the electrode system. Such constructions have long been used in high power transmitter valves, where the anode is constructed as a part of the envelope in order that it may be cooled more easily. In the case of receiver valves also such a construction, the so-called "Catkin" valve, was designed in England. This valve was, however, not manufactured on a large scale and after some time it disappeared from the market.

a hole in the centre of the header in which a metal exhaust tube with a small flange is welded for the evacuation of the valve later on.

Lead-in wires are sealed into the "Fernico" eyelets (coefficient of expansion 48 to $50 \times 10^{-7}/^{\circ}\text{C}$) with the help of the above-mentioned hard glass with low coefficient of expansion. These leads consist of three parts: an internal nickel support for welding the electrodes of the system, a short section of molybdenum wire for the vacuum-tight lead-in and a nickel or copper wire for the connection to the pins of the base, which in this case is constructed as a bakelite "wafer type" base plate with pressed-in pins. In this case a "holder" is therefore not superfluous, nor is the soldering of the leads in the pins. From the electrical point of view also this is a disadvantage, for instance with the high frequency losses and the frequency-drift during the heating-up period.

After the leads have been sealed in, a series of manipulations follows before the electrode system can be welded on the header, and only after that has been done can the iron envelope be welded to the base plate by means of a very heavy projection welder⁴⁾ which produces a vacuum-tight weld. The valve is then ready to be exhausted.

It may be noted that the protection of the exhaust tube which is squeezed, welded and cut off, after the exhausting and de-gassing, is provided by a central spigot which at the same time locates the valve in the socket correctly.

A variant of this model, of which it was hoped that it would be less expensive than the construction described above, has the metal header replaced by a glass plate with sealed-in lead wires (nickel-iron core with copper covering). The glass plate is sealed into a chrome-iron ring which in turn is welded into an iron ring. The iron ring has the same function as the edge of the header of the model previously described, namely for the bulb to header weld. In this model the exhaust tube is not of metal but of glass; see *fig. 2*.

Originally in this model of valve the control-grid lead-out was at the top of the metal bulb as shown in the figure.

These valves were appreciably smaller than the glass valves previously manufactured with pinch construction, and due to the metal envelope a good

³⁾ The coefficients of expansion of glass mentioned in this article refer to average values which are measured in the temperature range between 20 and 320°C .

⁴⁾ A projection welding apparatus is a resistance welding apparatus with which the parts to be welded can be joined on an accurately defined surface by a welding impulse of very short duration and considerable power.

shielding of the electrode system against external fields was automatically obtained.

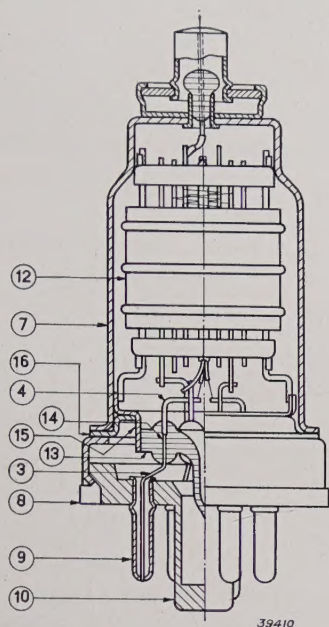


Fig. 2. Radio valve with metal envelope in which the metal header is replaced by a glass "button stem". For the meaning of the numbers see fig. 1, and further:

- 13. Glass button stem,
- 14. Lead-in wire,
- 15. Chrome-iron ring,
- 16. Iron ring.

In the meantime a new form of metal valve appeared in the European market (developed by "Telefunken"), in which the experience gained with the American construction was taken into account and several new ideas incorporated (see fig. 3). The principle of the metal header with "Fernico" eyelets and the insulated molybdenum leads through hard glass were here again used; a "base" in the form of a flat plate with moulded or pressed-in contact pins must also be used under this metal valve. The difference between this valve and the

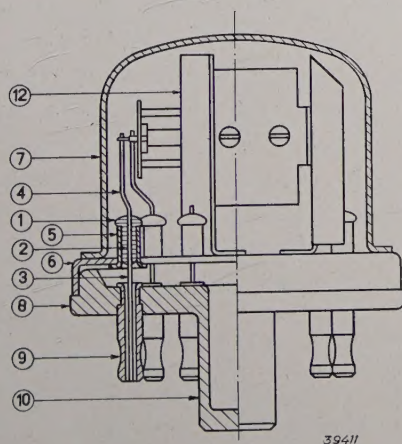


Fig. 3. European construction of the radio valve with metal envelope. The electrode system is placed horizontally. For the meaning of the numbers see fig. 1.

American model according to fig. 1 is that the electrode system is constructed horizontally, which permits a very solid construction, but with the accompanying (not inconsiderable) increase of the diameter. An advantage is that all the electrodes can have their leads on one side, namely to the bottom and without thereby increasing the anode-grid capacity⁵⁾ (single-ended construction). In a series of valves this capacity is very important, since it may be the cause of an undesired coupling of anode and grid circuit. In modern set construction it is required that this capacity shall not exceed the extremely small value of 0.002 pF, a requirement which can immediately be fulfilled with the new form of metal valve.

Technically this construction is satisfactory in all respects, it has, however, various disadvantages, for example the fairly large diameter and the fact that power-output valves and rectifier valves of the power as used in the broadcast-field cannot be made according to this design because of the limited length of the cathode (due to the horizontal construction). For these types of valves a vertical construction would again be necessary. It is for this reason that this metal range consists chiefly of radio-frequency, frequency-changing, intermediate-frequency, detector and low-frequency amplifier valves, while output valves and rectifiers belonging to this series are manufactured in the old familiar pinch technique, but with the same base as the metal valves.

The all-glass key valves

In the meantime work has been done at Philips on an improvement in the construction of the glass valve. The requirements upon which this improvement was based are briefly the following:

- Small dimensions,
- Good shielding,
- Reproducibility in manufacture,
- Good contact and firm fastening of the valve in the valve holder,
- Low consumption of material and preferably use of materials which can be easily obtained.

In order to simplify the manufacture it is furthermore desirable that the valve should have no base, but the leads should be in one piece and serve also as contact pins.

⁵⁾ Later this design with all connections on the same side was also applied in America to the constructions represented in figs. 1 and 2. This was done by bringing the grid lead from the top to the bottom and introducing extra shielding in order to prevent the anode-grid capacity from becoming too large. This capacity is, however, much larger than that of the European metal valve construction described.

The result was the modern all-glass valve construction described in the article referred to¹). It is chiefly distinguished by the use of pressed glass and thick chrome-iron contact pins, which make it possible to omit the "holder" which is in many respects so undesirable. In connection with the form and the function of the spigot these valves are called key valves (see fig. 4).

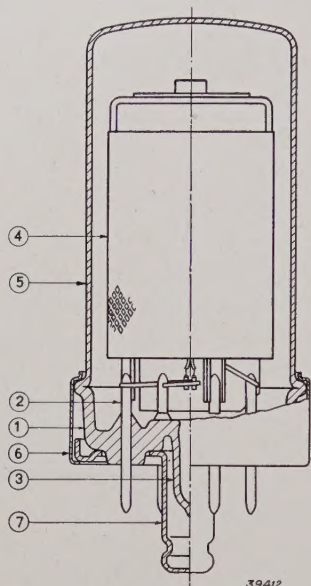


Fig. 4. Cross section of an all-glass Philips key valve. The sealed-in pins make direct contact in the socket; the bakelite base present in previous valves is eliminated.

- | | |
|------------------------|------------------|
| 1. Pressed glass base, | 5. Glass bulb, |
| 2. Chrome-iron pin, | 6. Metal ring, |
| 3. Glass exhaust tube, | 7. Metal spigot. |
| 4. Electrode system, | |

The model in which originally a series of special valves (particularly for television and other special purposes) were manufactured, still had a rather large diameter (envelope about 30 mm; largest diameter about 34 mm), but the use of these valves already meant a considerable saving of space on the surface of the chassis compared with the use of the metal valves with a diameter of 43 mm.

From this model with nine pins the modern glass key valve was developed with eight pins, an envelope diameter of about $27\frac{1}{2}$ mm and a largest diameter of about $31\frac{1}{2}$ mm. The central spigot in these valves is of metal and serves not only as centering and locating device in inserting the valve into its socket, but at the same time as shielding between anode and control-grid pin. This spigot is so arranged that the valve clicks into the socket, which is a great advantage for the locating device if the set is to be transported complete with valves; a requirement which at present is universal.

This construction also makes it possible to obtain a grid-anode capacity which is smaller than

0.002 pF in spite of the vertical assembly, the small diameter and the single-ended construction. The object of making smaller and smaller valves in connection with the demands of the set-makers is fully met by this construction. The development of the Philips midget receiver, type 203 U, which although equipped with four valves, has a volume of only 5 dm³, was only possible because of the existence of such valves.

Properties of glass and metal valves

The advantages of the all-glass valve compared with the valves with a pinch have already been discussed in detail in the article cited¹), and it is these properties which make them particularly suitable for use in the region of ultra short waves. The shorter the wave length, the greater the advantages. In the television region (wave lengths of several metres) the properties are already important, at still shorter wave lengths (decimetre waves) they may even become of such value that a pinch construction need no longer even be considered.

We shall now compare several properties of the glass key valves with those of metal valves.

During the heating up period of the valves in a set, the capacity variations which occur due to the change in the dielectric cause a frequency drift of the set which has previously been pointed out. At broadcasting wave lengths this frequency variation may already be somewhat disturbing; but with the decrease in the wave length it becomes steadily more important. While with the glass key valves a decrease of the frequency variation by a factor 2 (at 15 m wave length) compared with the pinch construction was obtained, with the metal valves this advantage is again lost.

A second disadvantage of the metal valves is that in the construction described the leads sealed into the eyelets involve a rather large concentrated capacity, whereby at wave lengths shorter than 1 m an appreciable depreciation in the results, which can be obtained with the valves is noticeable, and below about 50 cm even makes their use impossible.

A third point of difference relates to the input and output damping. In the case of the glass valves this is lower than in the metal construction, since the dielectric losses of the capacities between the leads and the metal envelope furnish an extra contribution to this damping. Because of this a greater amplification can be obtained with glass valves at wave lengths in the metre region.

It is clear that all these points of difference relate to the short-wave properties. In the case of the

ordinary broadcasting receivers, however, they are of no great importance.

As a matter of fact the metal valve has the advantage already mentioned of providing a better shielding against external fields. In the case of the glass valve this shielding must be obtained by building in a so-called cage of metal gauze (at least for those types where shielding is necessary), which encloses the whole system — a device which is satisfactory in all respects.

Another important point, which is of importance not only in the glass but also in the metal construction, is that of the high-frequency losses of the leads in the ultra short wave region. The D.C. resistance of the solid pin is hereby of secondary importance, because the high-frequency resistance depends mainly upon the condition of the surface layer. With given dimensions of the lead the following values were measured at a wave length of 90 cm:

silver wire	0.12 Ω
copper wire	0.12 „
aluminized iron	0.20 „
molybdenum	0.23 „
tungsten	0.26 „

A grade poorer are:

nickel	1.20 „
iron	3.60 „
“Fernico”	5.20 „
chrome-iron	6.00 „

From this it will be clear that if pins of the last mentioned materials are copper-plated or silver-plated, considerable improvement can be obtained. Thus, for example, with a given lead-in, thin silver-plating of the chrome-iron wire gave an improvement of the high-frequency resistance from 1.1 Ω to 0.13 Ω for $\lambda = 1.0$ m, while in another case an improvement from 1 Ω to 0.17 Ω was obtained by copper-plating the wire.

A metal key valve

From the above considerations it follows that in principle it must be possible to design a metal valve for the broadcasting field which satisfies the requirements specified in the introduction. Such a valve may be considered as equivalent in practical use to the glass key valve construction described. It is possible therefore to be more or less independent of the supply of a given raw material, factory equipment, etc. The solution of this problem is shown in the valve construction given in *fig. 5*. As to dimensions this valve is identical with the all-glass key valve described: the contact pins are also in the same relative positions to each other, there is also a spigot, its over-all dimensions are the same, and the same electrode systems can be used in it; briefly it is a design with which it is possible to make replicas of existing all-glass types. The components of this type are shown in *fig. 6*. The capacities between the electrodes (for instance

input and output capacities) will of course differ slightly from those of a similar type in all-glass construction, but these differences are so small that they can be compensated very easily by trimming the set. In many cases it will even be possible to replace the valves in existing sets without any change.

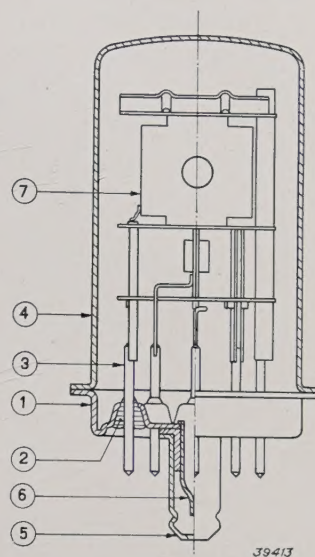


Fig. 5. Cross section of a metal key valve. The external dimensions, the arrangement of pins and the construction of the electrode system are exactly the same as in the glass key valves.

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|------------------|------------------------|
| 1. Metal header, | 5. Metal spigot, |
| 2. Glass bead, | 6. Metal exhaust tube, |
| 3. Iron pin, | 7. Electrode system. |
| 4. Metal bulb. | |

The new metal valve consists in principle also of a header (see *figs. 5 and 6*) with small holes for the vacuum-tight sealed-in leads, while there is an opening in the centre for welding the exhaust tube into the header. The advantage of this construction compared with that according to *fig. 3* is, that due to the strong vertical construction in which, just as in the all-glass valves, several U-shaped supports provide the necessary mechanical strength, the length of the cathode may be chosen in accordance with the type of valve to be made. Power-output valves, rectifier valves, special combination valves, etc. can therefore also be made in this construction.

The iron header is subjected to several special treatments before the eight leads are sealed-in at a temperature of about 950 °C. A glass bead is previously fused around each pin, the glass of which is adapted to the lead wire and the iron header. The pins may then be of ordinary iron or of an iron alloy. In both cases they are subjected to a special surface treatment before sealing-in.

Upon comparison with the previously described

metal construction it is obvious that the quality of this seal must be very high, not only with regard to vacuum tightness, but also to that of mechanical strength, accuracy and precision. The electrode system of the valve must be welded to the pins on

expansion, *viz.* about 103×10^{-7} , and it is fused into a soft glass with a slightly lower coefficient of expansion. This glass has a much lower softening temperature, namely about 475°C .

Since this chrome-iron to glass seal satisfies

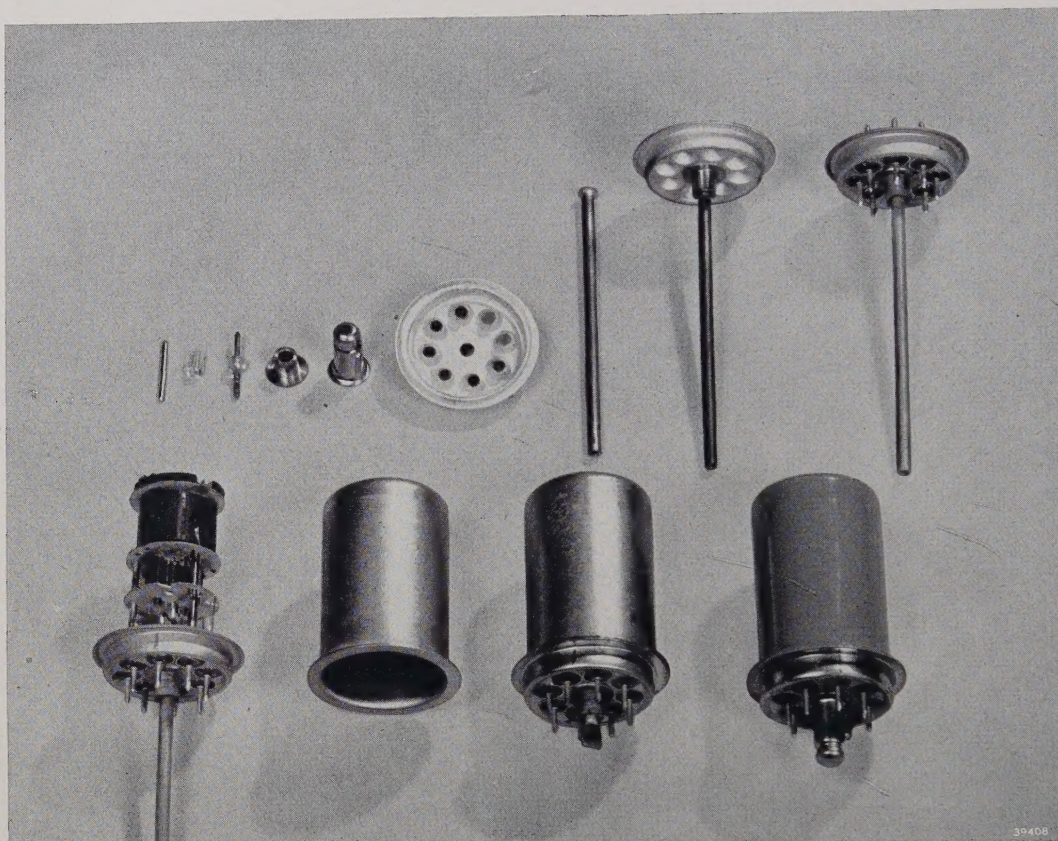


Fig. 6. The parts of the metal key valve in different stages of manufacture. Upper row, left to right: one of the 8 fused-in leads; glass tube to make bead; bead fused on pin; "cap" upon which the spigot is later welded; spigot; metal base plate with holes; metal exhaust tube; combination of base plate, exhaust tube and cap complete the base plate with fused-in pins. Lower row: electrode system assembled and mounted on the pins; metal envelope; valve after being exhausted and finally the completed valve.

the inside of the valve, and on the outside of the valve (when inserting it in its socket) fairly strong forces are exerted on the pins. The technical problems which are encountered in making those leads are not simple and require a thorough knowledge of glass-metal seals and wide experience. A brief comparison of the different techniques used in the constructions previously described gives the following picture.

In the case of the sealing in of a thin molybdenum wire (coefficient of expansion 51×10^{-7}) to give a vacuum-tight seal and to be insulated in a "Fernico" eyelet (coefficient of expansion 48×10^{-7}) a glass is used with a coefficient of expansion as close as possible to the above. A hard glass has been used with a softening temperature of about 540°C ⁶⁾.

In sealing the solid chrome-iron pins in the glass key valve, the pin has a much higher coefficient of

high requirements as to quality and reproducibility, it would seem obvious that the header of the metal key valve as well as the pins should be made of chrome-iron. This would indeed be excellent were it not for the fact that the cost of such a header would be too high for normal use. Therefore an attempt was made to use cheaper and more easily obtainable metal. It was for this reason that iron was chosen for the new construction, with its appreciably higher coefficient of expansion: 125×10^{-7} . This makes it necessary that the glass should again have a higher coefficient of expansion.

Although in general soft glass is easier to work

⁶⁾ The softening point is defined as the temperature at which a glass rod 30 cm long and 4 mm in diameter, supported at each end, bends 2 mm under a weight of 195.5 g. The melting point is much higher.

with than hard glass, soft glasses with such high coefficients of expansion introduce difficulties in manufacture among which is the chemical decomposition of these lead glasses during the life of the valve, not only by atmospheric influences but also by the formation of "lead trees" due to electrolysis of the glass. Moreover, in the short period during the sealing-process (at a temperature of about 950 °C) reduction of the lead oxide may occur resulting in surface conduction.

A satisfactory solution of these problems has been found and a manufacturing process worked out for the surface treatment of the metals and the sealing-process which meets these objections.

It is also important that the construction should be such that as far as possible the glass will be under pressure stresses only and under all conditions of use, since only under these conditions can an adequate guarantee be obtained of a mechanically strong and at the same time vacuum-tight seal (no cracks, no leaks).

When we study the stress diagram of such a complete header it will usually be evident that only pressure stresses do occur in the seal of glass to base plate, and at the pin, axial pressure and tangential pressure is combined with radial tensile stress. It may, however, also occur that the stress diagram of the axial and radial stresses along the pin is reversed (axial tension and radial pressure stress). The whole picture becomes more complicated when it is kept in mind that variations in the coefficient of expansion of the glass are inevitable and that the wire and the header do not behave in the same way, due to the fact that the influence of the surface layer on base plate and pin is relatively different.

After the metal exhaust tube has been welded on the header and the pins have been sealed in, the header is nickel-plated. On the bottom of the header a small "cap" is welded which is used afterwards for the fastening of the spigot which also serves to protect the iron exhaust tube. The metal bulb is then welded on the header with a heavy projection welding apparatus, after the electrode system of the valve has been mounted and welded to the pins and the connections between the various electrodes and pins have been made.

The following figures will give some idea of the power needed for such welding. While for the previously described metal valve with a diameter of 43 mm a projection welding apparatus of nominally 400 kVA must be used (the power impulse during welding is actually of the order of magnitude of 1000 kVA; primary 500 V, 2000 A, secondary

about 110,000 A), for this construction a smaller apparatus can be used, of nominally 175 kVA (peak about 450 kVA). These welding machines are regulated by a special control device which makes it possible to vary the duration of the weld impulse continuously from about $\frac{1}{2}$ to about 25 cycles, and to set the welding current in 16 different positions by primary regulation. The welding pressure can also be regulated between 100 and 17,000 kg. The welding electrodes are developed for this purpose and are water-cooled.

The welding method described has the advantage over any sealing process that the attachment of the envelope to the base header takes place at room temperature (it is only necessary to dissipate the heat developed at the weld and this is relatively little due to the short duration of the weld impulse). Undesired oxidations in the inside of the valve are thus *a priori* avoided. In the case of glass sealing, on the other hand, in certain cases precautions must be taken such as the protecting of the interior of the valve with inactive gases like nitrogen or mixed gas.

The valve thus constructed can be exhausted and de-gassed in the ordinary way. The exhaust tube is then squeezed and sealed by welding.

It is obvious that in the case of a metal valve direct heating of the internal parts by means of high frequency is impossible. The heating of the internal parts for de-gassing purposes must therefore take place indirectly *via* the metal envelope or by partial heating from the inside by heating the filament, with or without the combination of electron bombardment of the grids, etc. For external heating of the envelope (the header and leads must of course be cooled at the same time) high-frequency heating is, however, unnecessary, and the heating can more economically be done locally by means of gas.

The getter for binding the gas residues can be very easily flashed by heating with gas flames from the outside, or by the passage of current, and it is then deposited on the wall of the envelope with the advantage that the layer of getter is connected to zero potential (and thus does not form a "floating" capacity).

Summarizing, it may be said that it is possible in the broadcasting region to eliminate the problem of a choice between "metal" or "glass", so that the existence of this alternative need have no effect on the further development of set construction. Only considerations of a practical nature (equipment present in a given factory, the availability of certain materials or other special circumstances) need in the future determine the choice of the technique to be employed.

ASSEMBLING GRIDS FOR RADIO VALVES



In triodes the interior of the valves consists of a cathode with a grid and an anode. Two grids are used in tetrodes, pentodes require even three, and so on.

Reproducibility and interchangeability of valves, and their characteristics, necessitates that the inter-spacing of these parts and their dimensions be always the same within very narrow limits. The assembling operations, consisting mainly in welding and pinching, are therefore onerous and precise and require many checks and random tests.

CARRIER-WAVE TELEPHONY

by D. GOEDHART and J. de JONG.

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In the case of telephone connections over long distances, where the cable and the repeaters connected to it represent an important part of the total expense, it is often advantageous to multiply the number of conversations which can take place simultaneously on one set of wires by the application of carrier-wave telephony. The principles of carrier-wave telephony and the general construction of an installation for this purpose are described in this article. From the functions of the different components the requirements which must be made of them are deduced, while the specific problems and the practical construction of the parts will be dealt with in future articles.

Introduction

The simplest way of bringing about a telephone connection between two subscribers *A* and *B* is to connect the microphone of *A* by means of two wires to the telephone of *B*, and the microphone of *B* by two other wires to the telephone of *A*. Four connection wires are hence needed (four-wire connection, *fig. 1*).

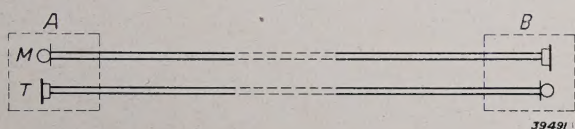


Fig. 1. Four-wire connection between two subscribers *A* and *B*.

Connections were very quickly worked out in which the number of connecting wires could be reduced by one half (two-wire connection, *fig. 2*). In each of the two telephone instruments there is then a so-called fork, an arrangement which sends the microphone currents over the line and the currents incoming from the line to the telephone.

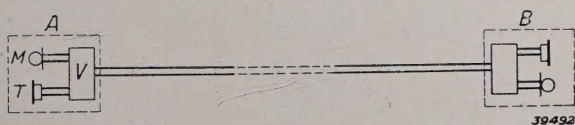


Fig. 2. Two-wire connection between two subscribers *A* and *B*. *V* forks.

Due to the damping caused by the connection wires the distance which can be linked in this way is limited. After the invention of amplifier valves, amplifiers (repeaters) could be placed in the connection line¹⁾, thereby making the distance covered many times greater (*fig. 3*). With this increase in the distance the connection line becomes

proportionally more expensive, while the costs of the terminal apparatus (microphone, telephone, fork) remain the same, so that the greatest part of the cost of the connection is due to the connection line.

If many calls must be transmitted simultaneously between two centres of population, the same number of pairs of connection wires with the necessary repeaters are required. These connection wires are usually combined into cables with many cores. By the application of carrier-wave telephony, however, different conversations can be carried on at the same time over one pair of connection wires. This makes the cost of the cable and the repeaters much lower. The apparatus at the beginning and end of the connection also becomes more complicated and therefore more expensive. From this it follows that the application of carrier-wave telephony is only justifiable economically for the bridging of long distances where the cable costs are the dominating factor; for small distances, for instance for local calls, the cost of the final apparatus would be too high and carrier-wave telephony will therefore not be used.

In two previous articles in this periodical^{1,2)} several problems of carrier-wave telephony have already been discussed. In this article we shall consider the general plan of an installation for carrier-wave telephony and the most important problems which occur in such an installation. The solutions

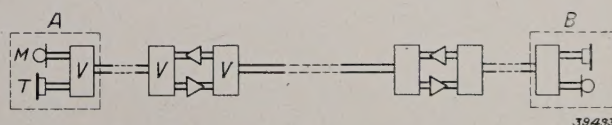


Fig. 3. If the distance between two subscribers *A* and *B* is great, repeaters are inserted in the line at regular intervals. Since repeaters give transmission in only one direction there are always two side by side, one for each direction, with a fork at each side in the case of a two-wire connection.

¹⁾ We do not here consider coil-loading by which means the distances bridged are also made greater. The subject is discussed in detail in: F. de Fremery and G. J. Levenbach, Carrier-wave telephony on coil-loaded cables, Philips techn. Rev. 4, 20, 1939.

²⁾ G. J. Levenbach and H. van de Weg, Non-linear distortion in loaded cables, Philips techn. Rev. 4, 79, 1939.

which have been found for the problems encountered, and the construction of the necessary parts will be discussed in following articles.

The principle of carrier-wave telephony

The vibrations occurring in speech may be considered as made up of a large number of sinusoidal vibrations with different frequencies and different amplitudes (actually an infinite number of vibrations, represented by a Fourier integral). For a satisfactorily intelligible conversation it is not necessary to transmit all these frequencies, but only those which lie between about 300 c/s and about 3000 c/s. The telephone cable can, however, transmit a much wider frequency region. The frequency region above 3000 c/s can now also be used for the transmission of telephone conversations by the use of a method which exhibits much analogy with that of radio technology.

A carrier-wave with a high frequency f_c is modulated in a transmitter with the low-frequency oscillations of speech. Due to this modulation two new groups of frequencies occur: the so-called side bands at either side of the carrier wave (fig. 4). The

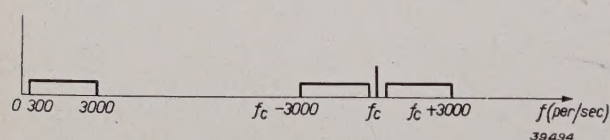


Fig. 4. Position in the frequency spectrum of the speech vibrations to be transmitted and of the carrier wave with two side bands.

upper side band (from $f_c + 300$ c/s to $f_c + 3000$ c/s) represents a shift of the frequency spectrum of 300 to 3000 c/s by an amount f_c , the lower side band (from $f_c - 3000$ c/s to $f_c - 3000$ c/s) is the mirror image of the upper side band with respect to the carrier-wave f_c . In this way a number of different conversations can be modulated, each on a carrier wave with a different frequency and all these modulated carrier waves can be fed to the common line.

If the frequency difference between the carrier waves is sufficiently great, then with a corresponding number of selective receivers connected at the other end of the line, each of the modulated carrier waves can be received without interference by the others. Just as in radio technology the ether transmits various programmes at the same time, in the same way in carrier-wave telephony a single pair of cores simultaneously transmits many conversations. It is clear that the efficiency of the cable is increased many times in this way.

If the same pair of cores is used for the transmission of conversations in both directions (two-wire connection, fig. 3) several complications result, since it is difficult to prevent mutual interference of the speech in opposite directions (see article ¹). Therefore the four-wire connection (fig. 1) is usually used in carrier-wave telephony. This, however, does not require more pairs of cores than the two-wire connection. It is found, that in the two-wire connection it is not easily possible to use the same carrier-wave frequencies for the two directions, because of the difficulties which the forks needed at each side of each repeater occasion at high frequencies. Each frequency region can therefore only be used once in a given pair of cores, either for one direction or for the other. The number of calls is then the same as if one half of the pairs of cores were used exclusively for one direction and the other half for the other direction (four-wire connection). Ordinarily two cables are laid side by side with equal number of pairs of cores, one cable for each direction.

It is not necessary to transmit both the side bands formed in the transmitter; one side band is enough. The receiver is capable of reproducing from the carrier wave and one side band the low-frequency vibrations which formed the original speech. With the help of a filter, therefore, at the transmitting end one of the side bands is cut off, which makes it possible to include in a given frequency region twice as many call channels, and the efficiency of the cable is thus doubled (fig. 5).

As indicated in fig. 3, here also repeaters are necessary at intervals in the cable. In order to be able to keep these repeaters small in spite of the large number of calls that must be amplified, the carrier waves, which would have to have a large amplitude, are themselves not transmitted (this can be accomplished by suitable connections of the modulator), but are added again in the receivers ³).

Arrangements and functioning of a carrier-wave telephone connection

Fig. 6 is a simplified diagram of a carrier-wave connection between two places *L* (left) and *R* (right). At *L* are the subscribers *A*, *C* and *E*; at *R* the subscribers *B*, *D* and *F*. *A* speaks with *B*,

³) In radio broadcasting, where the available frequency region is also occupied as fully as possible, both the side bands are always transmitted, in contrast to the case in carrier-wave telephony. If in that case only one side band were transmitted, the receiver would have to add the carrier wave again. This is not practicable for a receiver which must be capable of reproducing many broadcast transmitters. If one side band plus the carrier wave were transmitted the distortion which occurs at great depth of modulation would not be permissible. In carrier-wave telephony a carrier-wave with large amplitude is added in the receiver, so that the distortion remains small. Since the microphone and the telephone already give considerable distortion the slight increase in distortion due to the lack of the second side band is not disturbing.

C with D and E with F. Between R and L lie two pairs of cores, one for transmitting speech from

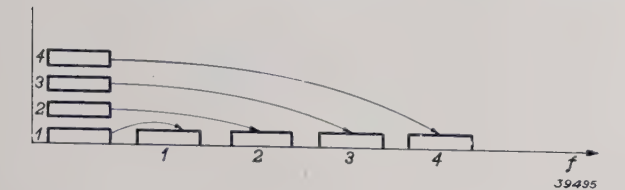


Fig. 5. Position in the frequency spectrum of the speech vibrations and the corresponding frequency regions to be transmitted in the case of a four-channel system with suppressed carrier wave and a single side band.

are unnecessary for intelligibility. The frequency region which remains is fed to a modulator *ModF*, to which the carrier wave with a frequency f_A is also fed. This modulator (which functions in the same way as the modulator in a broadcast transmitter) is an arrangement which gives at its output the two side bands without the carrier wave. Following the modulator is a transmission band filter *BFZ_A* which passes one of the side bands but suppresses the other. The band to be transmitted may be either the upper or the lower one.

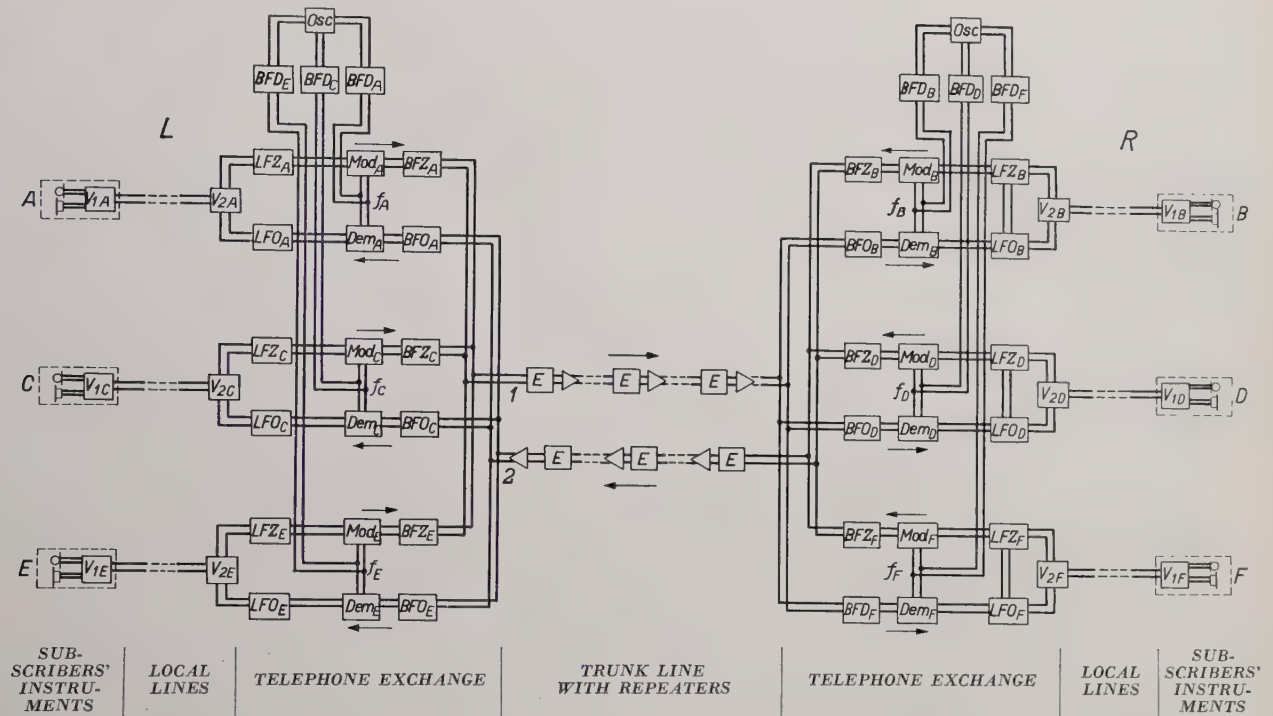


Fig. 6. Simplified diagram of a carrier-wave telephone installation for three speech channels. The subscribers' instruments consist of a microphone, a telephone and a fork V_1 , and are connected by means of the local line to a fork V_2 in the telephone exchange. Each outgoing call passes a low-pass transmission filter *LFZ*, a modulator *Mod* and a transmission band filter *BFZ*. All calls are then sent together over the trunk line, which contains at intervals an equalization network *E* with a repeater, to the other telephone exchange, where each call passes a reception band filter *BFO*, a demodulator *Dem* and a low-pass reception filter *LFO*. By way of the fork V_2 and the local line the call reaches the other subscriber. The carrier-wave frequencies in both telephone exchanges are derived from an oscillator *Osc* by means of the carrier wave band filters *BFD*.

L to R and one for transmitting speech from R to L. At the disposal of the subscribers are ordinary telephone instruments (microphone, telephone, fork) and they are connected to the telephone exchange by an ordinary two-wire connection. A subscriber wishing to make a call is connected, either automatically or by an operator, to an available fork V_2 in the same way as in ordinary telephony he is connected to an available line. The microphone current from A is sent through a low-pass transmitting filter *LFZ_A* which cuts off the frequencies above a frequency f_1 which

The microphone currents from C and E are treated in the same way, except that the carrier waves fed to the modulators have different frequencies, namely f_C and f_E . The output terminals of the three transmission band filters *BFZ_A*, *BFZ_C* and *BFZ_E* are connected in parallel. The cable thus transmits three frequency bands: from f_A to $f_A + f_1$, from f_C to $f_C + f_1$ and from f_E to $f_E + f_1$, when the upper side bands are chosen. At the receiving end (R) each frequency band must reach the correct channel and cause no inter-

ference in the other channels. The reception band filters BFO_B , BFO_D and BFO_F provide for this, each of which passes the correct frequency band but cuts off the others. Each of these band filters is followed by a demodulator to which the corresponding carrier wave is also again fed. Thus at the output terminals of the demodulator the original low-frequency band is produced, similar to that which was furnished by the microphone at the transmitting end (L), and in addition oscillators with higher frequencies. Each demodulator is followed by a low-pass reception filter which cuts off the undesired oscillations of high frequency. Via the fork V_{2B} and the local line the words of subscriber A now reach the telephone of subscriber B . In exactly the same way the words of B reach the telephone of A . In principle it is not necessary to use the same carrier-wave frequency for the conversation in the two directions between A and B ; in the case of a four-wire connection as represented in fig. 6, however, it is usually done for the sake of simplicity.

The number of connection possibilities between L and R is equal to the number of pairs of double wires present multiplied by the number of calls which can be transmitted per four-wire connection. This total number is made equal to the maximum number of conversations to be carried on simultaneously between L and R .

The subscribers' instruments undergo no change in carrier-wave telephony; the subscribers observe no difference whether their call is put through with or without carrier-wave telephony.

In the example of fig. 6 three subscribers have been assumed at each end (3-channel system). It is, however, clear that this number can be extended. A 12-channel system (12 calls over the same conductor) according to this simple principle making use of ordinary, non-loaded telephone cables¹⁾ is often used. Philips have, moreover, designed an installation with 17 channels on this principle. Fig. 7 is a photograph of part of the terminal apparatus necessary for this. If it is desired to transmit an appreciably larger number of calls over the same connection, a special cable is necessary and multiple modulation must be applied which necessitates a more complicated terminal apparatus (see below).

Choice of the carrier-wave frequencies

In order to make the most intense possible use of the available frequency region which the cable transmits without too great damping, the frequency difference between the carrier waves is taken as



Fig. 7. Photograph of a part of the terminal apparatus of the Philips 17-channel system.

small as possible. What now determines the necessary frequency difference?

As will be seen from the foregoing, the requirement is made of each band filter that it shall pass a certain frequency region and suppress a number of other frequency regions. Between the region of transmission and the damping region there is a transitional region where the damping is too high to permit satisfactory transmission, but too low to ensure sufficient suppression. Fig. 8 gives as an example the damping in dB as a function of the frequency for a band filter of the Philips 17-channel

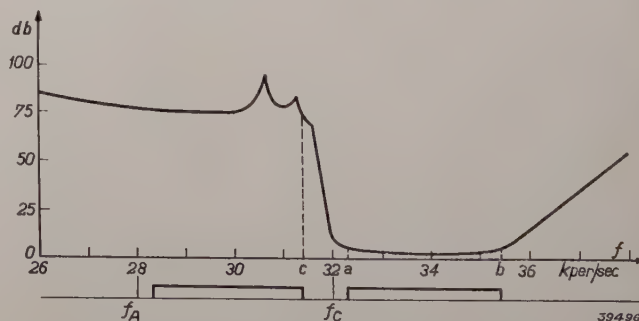


Fig. 8. Damping characteristic of a band filter. The carrier-wave frequencies of two neighbouring channels are f_A and f_C . The upper side band belonging to the carrier wave f_C fits into the transmission region of the filter (from a to b). The upper side band belonging to the carrier wave f_A falls in the damping region of the filter (below c). The region c to a is the transitional region of the filter.

system, in which the upper side band is transmitted. The transmission region extends from a to b . To the left of it from c to a is the transitional region which has a width of about 900 c/s. (An appreciably narrower transitional region would make very much higher demands on the construction of the filter). If we assume that the curve represents the damping of the transmission band filter $BFZC$ of fig. 6, then a must correspond to the lowest and b to the highest speech frequency of C to be transmitted, i.e. to f_2 and f_1 , respectively. The highest frequency of the neighbouring channel (the speech from A to B) may not be higher than c . The distance between the two highest frequencies of the neighbouring channels, which is of course equal to the distance between the carrier-wave frequencies, must therefore be at least $f_1 - f_2 + 900$ c/s.

We have already seen that as a rule the carrier waves are not transmitted, but added to the transmitted side band again upon demodulation. It is then necessary that the carrier-wave frequencies should correspond exactly at the transmitting and receiving ends. Now in order not to require many oscillators at the receiving end as well as at the transmitting end, each of which must furnish an accurately determined frequency, one oscillator is placed at the transmitting end and one at the receiving end, whose frequencies are carefully kept constant, and the other carrier-wave frequencies are derived from these by frequency multiplication. The frequency of these oscillators is therefore chosen equal to the frequency difference between the carrier waves, namely at least $f_1 - f_2 + 900$ c/s.

As lower limit f_2 of the frequency region to be transmitted the already mentioned value of 300 c/s is generally chosen. The lower the upper limit f_1 is taken, the smaller the necessary carrier-wave distance, but the poorer the intelligibility of the speech. If necessary $f_1 = 2600$ c/s would suffice. In order, however, to be able to obtain a better quality of reproduction, and guided by the desire to have round numbers for the carrier-wave frequency (in order to be able to compare these frequencies simply with the standard frequency present in every telephone exchange, which is very precisely 1000 c/s), the choice of the carrier-wave frequencies has been determined as integral multiples of 4000 c/s⁴). From this it follows that the highest speech frequency to be transmitted may amount to $4000 - 900 + 300 = 3400$ c/s.

In the case of the installation designed by Philips

for 17 calls, the lowest carrier-wave frequency, in agreement with the above, is 4000 c/s and the highest 68,000 c/s.

Cross talk

A first requirement in telephony is that each subscriber shall be able clearly to understand the speech intended for his ear, undisturbed by a background of interfering noises from conversations not intended for him. What a subscriber may hear of such noises is called cross talk. In the use of carrier-wave telephony the danger of cross talk is naturally greater than in other cases.

If the frequency spectrum of a call reaches the wrong subscriber in its original form, it is called intelligible cross talk, since with sufficient intensity the conversation can be understood. If this frequency spectrum, in its unwanted transmission, is, however, so distorted that it is impossible to follow the conversation even with sufficient intensity, it is called unintelligible cross talk. It is clear that for the sake of privacy the intensity of intelligible cross talk must be so low that it is absolutely impossible to follow the unintentionally overheard conversation. For this purpose the intensity of intelligible cross talk must be at least 70 dB below the intensity of the required transmission. Unintelligible cross talk does not violate the subscribers' privacy, but manifests itself as a disturbing background noise. An intensity about 60 dB below that of the required conversation is the limit permissible for this in practice.

It is mainly the filters which must prevent cross talk.

Requirements which must be satisfied by the parts of a carrierwave telephone installation

It may be seen from fig. 6 that the installation for carrier-wave telephony consists chiefly of cables, repeaters, oscillators, modulators and demodulators, forks and filters. Certain requirements must be made of each of these components for a satisfactory functioning of the installation. We shall consider these requirements in the following.

a) Cables

A coil-loaded cable is unsuitable for the transmission of the high frequencies necessary for a 12 or 17-channel system, due to the existence of a cut-off frequency (fig. 9) (see article¹). Fig. 9 also shows the damping of an ordinary non-loaded cable in dB per km length of cable as a function of the

⁴) On the recommendation of the C.C.I.F., Oslo 1938.

frequency. The damping in the frequency region to be used (4 to 72 kc/s) increases with the frequency. Per km length of cable the difference in damping between the lowest and the highest channel (4 and 72 kc/s, respectively) is 1 dB. For

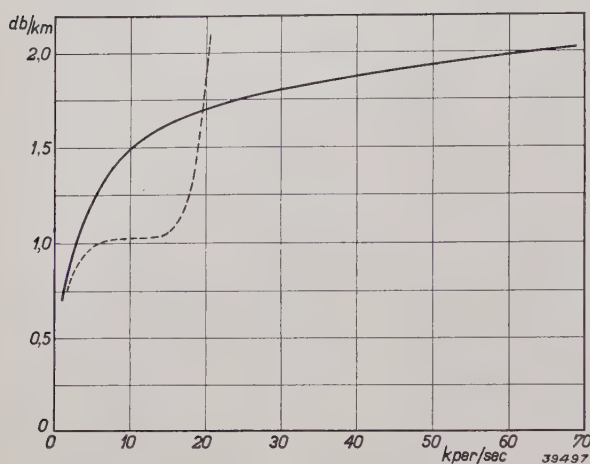


Fig. 9. Damping in dB per km as a function of the frequency for a normal, non-loaded cable. For the sake of comparison the variation of the damping is also indicated (broken line) for a lightly loaded cable.

a length of cable of 300 km (a fairly normal length for carrier telephony) this difference in damping is thus 300 dB. In connection with the combating of cross talk, however, the requirement is made that all calls shall be transmitted with about the same intensity. For this purpose so-called equalization networks are connected in series with the cable. These are quadripoles built up of resistances, self inductions and capacities in such a way that they give a high damping for the low frequencies and a low damping for the high frequencies, with the result that the damping of the cable plus the equalization network is practically the same for all frequencies considered. These requirements cannot practically be fulfilled with a single equalization network: the difference in damping at the lowest and the highest frequency is too great for that. Therefore the cables are divided into sections of such a length that it is practically possible to make the damping of each of these sections independent of the frequency with the help of one equalization network.

b) Repeaters

The damping provided by the cable with the equalization network must be eliminated again by repeaters. In the case of fairly long connections, however, it is impossible to achieve this with a single repeater either at the beginning or at the end

of the line. With a cable length of 300 km and a damping of 2 dB/km a total of 600 dB of amplification is needed. If a single repeater were placed at the end of the line, then with a normal value of for instance 1 volt at the beginning, the voltage at the end of the cable would be 10^{-30} volt. But the noise voltage is of the order of 10^{-7} volt per speech channel; the speech, even after sufficient amplification, would be inaudible because of the fact that the noise voltage is 10^{23} times as high. The voltage of the signal must in fact be much higher than the noise voltage at every point in the cable, because if the ratio between signal and noise voltage has once become too small, no improvement is possible by amplification. Therefore, before the signal voltage has fallen too low due to cable damping, a repeater must be introduced. If the requirement is made that the signal-to-noise ratio must be at least 1000 at the end of the cable, it is found that a repeater must be inserted in the cable approximately every 30 km (with an amplification of about $30 \times 2 = 60$ dB).

It is a fortunate circumstance that this cable length of about 30 km is not too great to be able to make the damping independent of the frequency with a single equalization network. An equalization network is consequently placed as a rule at the end of each cable section.

The amplification may not be appreciably affected by spontaneous changes in the repeaters (decrease in the slope of the amplifier valves due to age, etc.). If for example the amplification of each repeater should decrease merely 1 dB (*i.e.* about 10 per cent), then with 10 repeaters in a line the total amplification would decrease 10 dB, which is not permissible.

Each repeater must amplify simultaneously all the calls transmitted. This makes very high demands on the linearity of the repeater. If the output voltage were not sufficiently accurately proportional to the input voltage, A.C. voltages with combination frequencies would occur, which cause mutual interference of the channels, and in addition under certain circumstances cross modulation, with the result that a subscriber would be able to hear conversation not intended for him.

By the application of inverse feed-back in the repeaters the requirements mentioned can be satisfied.

The cable damping depends upon the temperature. The amplification must therefore change in a direction opposite to the change in temperature. A temperature compensation, preferably automatic, is therefore necessary.

c) Oscillators

If the corresponding carrier-wave frequencies differed at the transmitting and receiving ends, the frequency spectrum of the speech would be shifted at the receiving end. This causes distortion and, with any large degree of frequency shift, unintelligibility. In practical cases in the transmission of the spoken word a frequency difference of not more than about 10 c/s between the corresponding carrier waves at transmitting and receiving end is permissible. For a carrier wave of 68 kc/s therefore a discrepancy of only about 0.015 per cent is allowed. The oscillator of 4 kc/s from which the carrier waves are derived may therefore also not vary by more than 0.015 per cent, i.e. about 0.05 c/s upon variations in the supply voltage, the temperature, etc.

The different carrier waves are derived from this 4 kc/s oscillator by using the successive harmonics. Each carrier wave must, however, be sinusoidal; if the carrier wave, which is fed to a given modulator or demodulator, contains a component with the frequency of one of the other carrier waves, this may lead to cross talk (intelligible as well as unintelligible). Therefore the filters which sift out the different carrier-wave frequencies (*BFD* in fig. 6) must satisfy fairly high requirements.

d) Modulators and demodulators

The microphone current and the carrier wave are fed to the modulator; at the output terminals the two side bands without the carrier wave are desired. In order to accomplish this the modulator contains two or more non-linear elements (cuprox or selenium rectifiers⁵⁾ for example) in push-pull connection. An asymmetry in this connection will cause the appearance of undesired components in the output voltage. Great care must therefore be taken to secure symmetry; moreover, this symmetry must be retained in spite of temperature fluctuations and ageing.

e) Forks

Let us consider the closed circuit in fig. 6: V_{2A} -ModA- line 1-DemB- V_{2B} -ModB-line 2-DemA- V_{2A} . In this circuit there are, among other elements, a number of repeaters. There is therefore the danger that, following the circuit around, the total amplification will be so high that spontaneous oscillation may occur. To prevent this, care must be taken by means of accurate construction that the

currents reaching the fork from the reception channel are unable to reach the transmission channel, and are fed exclusively to the local line.

f) Filters

The filters form one of the most important parts of the whole installation. Their function is to provide that each subscriber receives the calls intended for him in a satisfactorily intelligible form and to prevent cross talk. In order to determine the requirements which every filter must satisfy the spectral distribution is ascertained of the interference caused by the calls not intended for him which each subscriber would receive if no filters were introduced. From this the minimum damping can be found which the filters must provide for the different frequencies in question, in order that the cross talk may remain below the limits previously mentioned. The filters, for instance, which are passed on the path from *C* to *B* in fig. 6, and which together, therefore, must provide this damping, are: the low-pass transmission filter *LFZC*, the transmission band filter *BFZC*, the reception band filter *BFOB* and the low-pass reception filter *LFOB*. The required total damping may to a certain extent be divided among these four filters in different ways; the most economical solution will of course be chosen.

In the determination of the required total damping curve several other factors must be taken into account. The microphone furnishes not only the frequency region to be transmitted of 300 to 3400 c/s, but also higher frequencies occurring in speech. On the other hand the microphone and the telephone are less sensitive to the high frequencies than to the lower ones; moreover, the intensity of the higher frequencies in speech is less than that of the lower, the ear is also not equally sensitive to all frequencies. Taking all these facts into account the damping caused by the filters may be lower for the higher audio-frequency vibrations than is necessary for the lower.

Due to temperature variations the self-induction and capacities of which the filters are built up will change and the cut-off frequencies will therefore shift. The filter elements should therefore possess only a very small temperature coefficient.

As to the transmission region, the damping of the filters must be practically constant for all frequencies. Due to losses in the coils and condensers of which the filters are composed, the damping becomes greater for the frequencies close to the limits of the transmission region than for frequencies in the middle of this region. It is therefore

⁵⁾ W. Ch. van Geel, Blocking-layer rectifiers, Philips techn. Rev. 4, 100, 1939.

necessary that these coils and condensers should be of good quality. Moreover, a transitional region of only 900 c/s, as assumed above, can only be attained when the losses in the filter elements are not too high.

Multiple modulation

In the case of the above described installation for carrier-wave telephony a frequency difference of 4000 c/s was assumed between the successive carrier waves. The transmission region of the band filters is the same for all channels. At higher carrier-wave frequencies therefore the relative width of the transmission region (*i.e.* the difference between the cut-off frequencies divided by the mean of the cut-off frequencies) becomes steadily smaller. The smaller this relative band width, the greater in practical cases is the difference between the damping at the edge and that at the middle of the transmission region, as a result of the losses in the coils and condensers (*fig. 10*). At the same time at

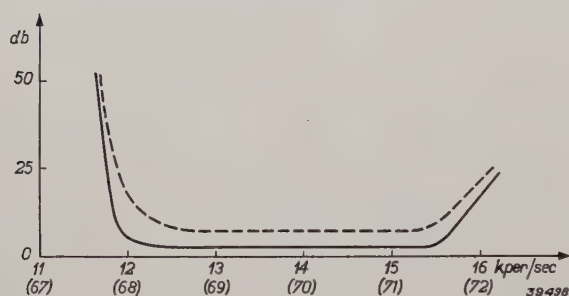


Fig. 10. Damping curves for the transmission region of two similarly composed filters with the same band width, but in different frequency regions. Full-line curve: band filter for the upper side band of a carrier wave of 12 kc/s; broken-line curve: same for a carrier wave of 68 kc/s.

higher frequencies greater accuracy is required in the realization of the correct values of self-inductions and capacities and in keeping parasitic impedances small, while the influence of temperature variations also becomes greater. For all these reasons it is in practice impossible to use carrier-wave frequencies higher than 70 kc/s in the way indicated.

Special modern cables are, however, capable of transmitting much higher frequencies (*fig. 11*). If it is desired to use this higher frequency region also for telephony, it is only possible to do so by the application of multiple modulation. This can for instance be done in the following way.

The calls to be transmitted are divided into groups of 12. Each of 12 calls is modulated in the way described above on carrier-waves with frequencies of 16 to 60 kc/s, so that — upon the use of the upper side band — each group occupies the

frequency region from 16 to 64 kc/s. Just as the frequency region of each conversation is shifted in the frequency spectrum by modulation, the frequency region of each group of twelve is now shifted

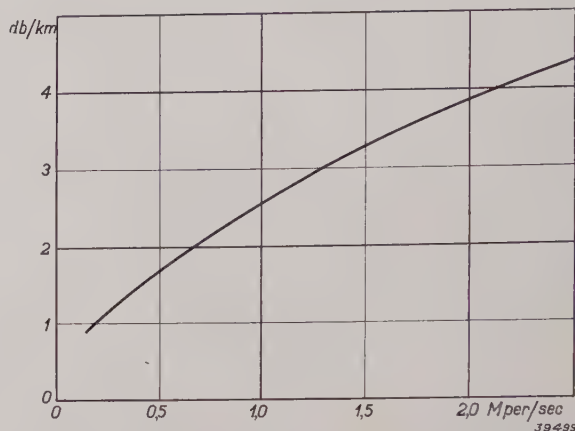


Fig. 11. Damping in dB per km as a function of the frequency for a modern coaxial cable.

by a second modulation by such an amount that the first group falls in the frequency region from 200 to 248 kc/s, the second group in the region from 248 to 296 kc/s, and so on. For 240 conversations, for example, the frequency region from 200 to 1160 kc/s is needed in this way. At the receiving end all the groups are first brought back into the region of 16 to 64 kc/s by a first demodulator, and next each conversation is shifted by a first demodulator, and then each conversation is shifted by a second demodulator into its original low-frequency region. After every second modulator a second band filter is now necessary, likewise after every first demodulator, but much less severe requirements may be made of these filters than of the first band filters, in the first place because the relative band width is high, and in the second place because the frequency difference between the side band to be passed and that to be suppressed is large so that the transitional region of the damping curve may also be wide. These filters may therefore be very simple.

In most cases, with such a large number of channels it will even be preferable to apply a third modulation for the sake of the greater simplicity of the band filters (*fig. 12*). For example, ten calls are first combined into a group which occupies the frequency region between 30 and 70 kc/s, and then five of these groups are joined to give a new group (super group) which occupies the frequency region from 300 to 500 kc/s and contains $5 \times 10 = 50$ calls, and finally eight of these last super groups are put side by side in the frequency spectrum by a third modulation in the

region from 500 to 2100 kc/s, so that $8 \times 50 = 400$ calls can be transmitted simultaneously.

Double modulation is also applied in the case of a small number of channels. The first modulation shifts all the calls to the same, higher, frequency region, whereupon the second modulation places

requirements are made of them; the second are simple filters. Since it is sometimes desirable for factory purposes that the more complicated filters should all be alike, the more complicated construction of the whole installation is sometimes preferred.

Transmission of the selector signals

Since at the present time there is a desire that not only the local connections in the telephone network but also the long distance connections between subscribers should be made without the help of a telephone operator, it is obvious that this requirement is also made of carrier-wave telephony. In ordinary telephony this is done by the subscriber making the call who sends a number of impulses to the automatic switches (selectors). Upon the use of carrier-wave telephony these impulses must first be converted in the telephone exchange into high-frequency oscillations, then transmitted by the cable and at the receiving end, after having been converted into a suitable current, they must operate the automatic selectors.

Carrier-wave telephony applied to a radio connection

In conclusion we should like to point out the possibility of transmitting different calls simultaneously with a radio connection also. To do this the currents which are sent through the cable in the carrier-wave telephony just described are modulated on the carrier wave of a transmitter (which must have a considerably higher carrier-wave frequency than the highest frequency to be transmitted), and at the receiving end this modulation is brought back again to the original position in the frequency spectrum. The four-wire connection is thus replaced by a radio transmitter and receiver at each end; the rest of the apparatus remains the same.

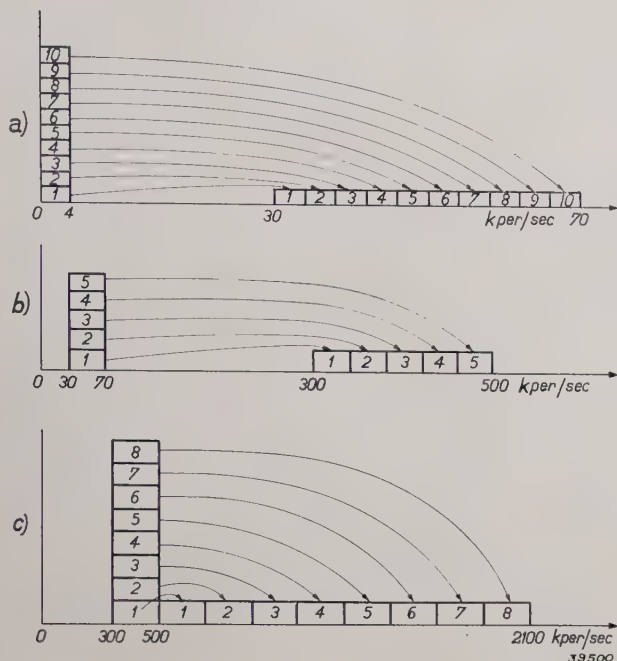


Fig. 12. Displacement of the speech vibrations in a system with triple modulation for 400 speech channels.

- a) Position of the frequency bands after the first modulation for each group of 10 calls.
- b) Position of 5 groups each of 10 calls before and after the second modulation.
- c) Position of 8 super groups, each of 50 calls, before and after the third modulation.

the different calls at the desired position in the frequency spectrum. After the first modulation the band filters are alike for all channels; after the second modulation they are different. The first band filters are the most complicated ones and high

IMPROVEMENTS IN THE EFFICIENCY OF ELECTRIC INCANDESCENT LAMPS

by W. GEISS.

621.326

By changing over from a single coil to a coiled coil filament in the case of argon-filled electric lamps an average improvement of 15 per cent was obtained in the efficiency of the lamps. Detailed investigations were carried out on ten different kinds of lamps specially made for the purpose on the effect of krypton instead of argon as a filling. From these investigations and from results of life tests of krypton-filled coiled coil electric lamps on the market it may be concluded that with the same life and luminous flux an improvement of about 3 per cent in the average efficiency could be obtained by changing over from argon to krypton. In connection with the cost of the krypton filling this improvement cannot be realized at once in practice.

Introduction

The steadily increasing need of better and more efficient illumination can be satisfied more successfully, the more efficient the production of artificial light. With the conversion of electrical energy into visible radiation in or by means of a gas discharge the large lamp factories have followed fundamentally new methods and have developed extremely efficient sources of light which have already found an important and partially even quite new domain of application. In addition to this important work, however, the laboratories of the industries in question have by no means neglected the further development and improvement of the electric incandescent lamp. During the last ten years various possibilities were carefully examined theoretically as well as experimentally, and have to some extent already been realized in a practical form. A survey of the results achieved will be given in the following.

Importance of a gas filling

In our discussion we shall start with the original publications¹⁾ on the gas-filled lamp. In these it was already shown that the characteristic properties of this lamp are determined by several physical constants of the filament and of the gas used for filling the bulb. If these constants are known the efficiency (Dlm/W) of a gas-filled lamp can be very accurately calculated. It is therefore possible to determine whether an accidentally favourable result obtained in a single experiment will also be obtained in practice.

The efficiency of a tungsten filament lamp, filled with gas and used in such a way that it will attain an average life of 1000 working hours is mainly dependent on:

- 1) the form of the filament,
- 2) the composition of the gas.

Research during the last ten years has been especially devoted to a study of this dependence and we shall here discuss the results in turn.

The form of the filament

An important possibility of improving the efficiency of gas-filled lamps, and one which has been investigated thoroughly, relates to the form of the filament itself²⁾.

Langmuir¹⁾ showed that the heat lost by a filament depends mainly on its length and only to a very limited extent upon its diameter, and at the same time that a coiled tungsten wire does not differ from a massive wire whose diameter is the same as that of the coil, as far as the loss of heat is concerned.

Instead of Langmuir's formula for the loss of heat the following empirical formula can very well be used:

$$W = C \cdot l \cdot d^{\delta} \cdot T^{\tau}, \dots \dots (1)$$

where

- W = the loss of heat to the gas,
- l = the length of the filament,
- d = the diameter of the filament,
- T = the absolute temperature of the filament and
- C = a constant depending on the gas mixture.

The exponents δ and τ are indeed again functions of the diameter and of the temperature, respectively, but they may be considered as constants within a wide range. It is found that the experimental values are best matched by choosing:

$$\delta = 0.3.$$

A large number of measurements which have been carried out during the last 15 years have confirmed this value of δ . At the temperatures mentioned in this article of 2500 to 3000 °K, τ is about 1.6.

¹⁾ I. Langmuir, Phys. Rev., 34, 401, 1912;
E. Oosterhuis, Chem. Weekbld., 14, 595, 1917.

²⁾ Cf. for example: W. Geiss, Philips techn. Rev., 1, 97, 1936.

For a given gas and for the temperature T , therefore, the ratio of conduction losses for two filament's of the dimensions $l_1 d_1$ and $l_2 d_2$ is

$$W_1 : W_2 = l_1 d_1^\delta : l_2 d_2^\delta.$$

If by means of a different form of filament it is desired to reduce the loss of heat to one half of that of an ordinary coil, the following relation must hold:

$$2l_2 \cdot d_2^{0.3} = l_1 \cdot d_1^{0.3}.$$

This means practically that the new filament must be slightly less than half as long as the first filament, but that it may be much thicker.

the average improvement obtained amounts to 10.7 per cent, while for the small types it even reaches 16 per cent. This advantage for the low-power lamps is important because of the fact that upon the introduction of gas-filling in 1913 the advantage lay with the larger types.

The employment of a tungsten wire whose form does not change has also had a very favourable effect on the properties of these lamps throughout their whole life. The decrease in luminous flux compared with that of lamps with single coil has fallen to less than one half, so that the average improvement of the efficiency throughout life is

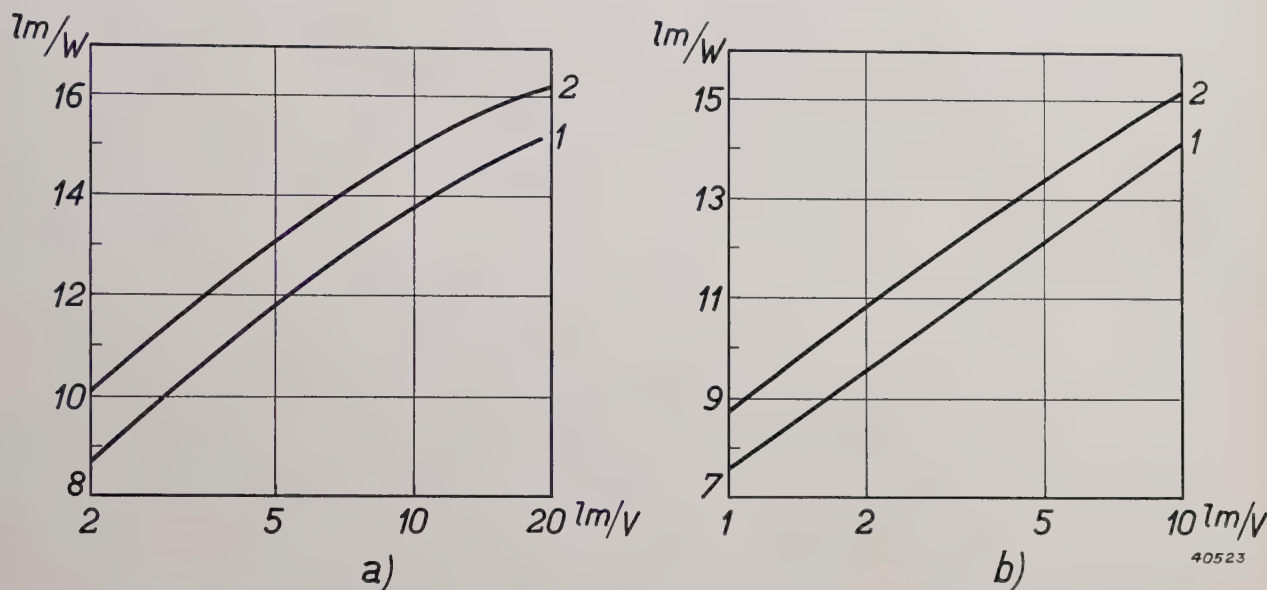


Fig. 1. The efficiency in lumens per watt for argon lamps with single coil filament (1) and coiled coil (2) as a function of the number of lumens per volt. a) is for lamps of 130 V and b) for lamps of 220–230 V.

This change in shape can be attained in two ways. A wire of the required length can be coiled on a mandrel with a diameter more than twice as great, which introduces great practical difficulties, or the ordinary coil can be coiled around a second mandrel giving the coiled coil.

In order to apply the second method, however, tungsten wire had to be available which retains its original form even at a high temperature. An elaborate investigation provided the lamp manufacturers with a solution of this problem.

On the subject of the lamp with the coiled coil, which has in the meantime been introduced everywhere and which in certain countries even occupies the foremost place, detailed articles have already appeared in this periodical²⁾ and elsewhere³⁾.

In fig. 1 may be seen the curves of the efficiency for argon-filled lamps with single and coiled coil as a function of the luminous flux per volt of lamp voltage. For the commonest sizes of lamps

still greater. According to the size of the lamps it amounts to 13–23 per cent and may be considered to average 15 per cent.

Rate of evaporation in a gas atmosphere

In addition to the form of the filament, its rate of evaporation in a gas atmosphere is very important for the efficiency of a lamp. The total radiation of a filament and the luminous flux are functions of the temperature. For their ratio E , namely the luminous flux divided by the energy radiated per second, in not too large a temperature region the following formula is sufficiently accurate:

$$E = aT^f \dots \dots \dots (2)$$

³⁾ W. Geiss, S. E. V. Bull., 26, 354, 1935; W. Köhler, Licht und Lampe, 24, 462, 1935; K. Moers, Das Licht 8, 17 and 43, 1938; K. Moers, Das Licht, 8, 130, 1938. On the basis of the last article it can be shown that the calculation of the heat losses according to Langmuir's formula agrees well with the measured values both for the single and the coiled coils.

In the same way for the rate of evaporation v of the filament:

$$v = \gamma T^g. \quad (3)$$

In these expressions a , f and g are material constants of the filament, while for a given form of the filament γ depends upon the nature and the pressure of the gas surrounding the filament. This constant will be smaller the more the gas atmosphere opposes the diffusion of the vapourized molecules of the filament. Therefore, for a given filament one may speak of a diffusion constant γ of the metal in the gas with which the lamp is filled.

If one starts with the experimentally confirmed assumption that a filament has reached the end of its life when a certain part of its weight has been evaporated, its life is inversely proportional to the rate of evaporation v . With a filament having a definite life (1000 hours for instance), therefore, the rate of evaporation in different gases will be the same. Therefore the following is valid for two gases with the diffusion constants γ' and γ'' :

$$v' = \gamma' \cdot T_1^g = v'' = \gamma'' \cdot T_2^g; \quad (4)$$

From this it follows that:

$$\frac{\gamma'}{\gamma''} = \left(\frac{T_2}{T_1}\right)^g. \quad (5)$$

The following is also valid:

$$\frac{E_2}{E_1} = \left(\frac{T_2}{T_1}\right)^f. \quad (6)$$

By combining (5) and (6) we find that

$$\frac{E_2}{E_1} = \left(\frac{\gamma'}{\gamma''}\right)^{\frac{f}{g}}. \quad (7)$$

From the literature it is known⁴⁾ that at about 2700° K the following values can be used:

$$f = 4.8 \text{ te } g = 34.3,$$

from which it follows that $f/g = 0.14$, so that

$$\left(\frac{E_2}{E_1}\right) = \left(\frac{\gamma'}{\gamma''}\right)^{0.14}. \quad (8)$$

From this formula it is found that a large change in the diffusion constant γ of the gas will only cause a relatively small change in E .

The diffusion constants of argon and nitrogen were determined as early as 1917⁵⁾, also as functions of the gas pressure, and from the measurements;

moreover, it was concluded that the efficiency could be improved by using a gas with a high molecular weight. The results of the measurements were later fully confirmed by experiments by Fonda⁶⁾ (see fig. 2).

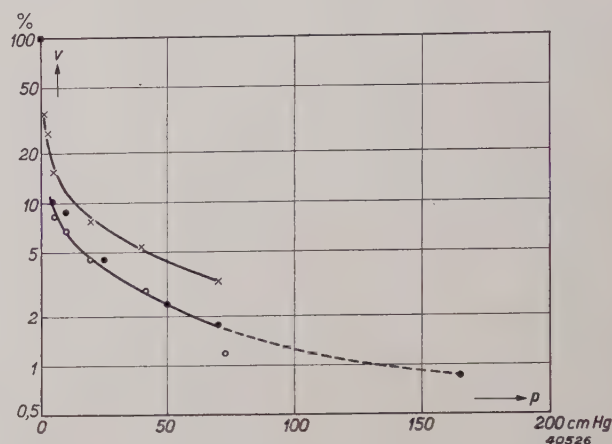


Fig. 2. Rate of evaporation v as a function of the pressure p (cm mercury), expressed in % of the rate of evaporation in a vacuum.

× nitrogen, according to Oosterhuis⁵⁾.

○ argon with 10% nitrogen, according to Oosterhuis⁵⁾.

● argon with 14% nitrogen, according to Fonda⁶⁾.

In addition Fonda⁷⁾ fixed the relation between the rate of diffusion and molecular weight in a formula, and pointed out that the calculation of the diffusion can be connected with Langmuir's theory of heat losses.

In this theory it is assumed that the cylindrical filament of thickness d is surrounded by a cylindrical film (Langmuir layer) of diameter b in which the gas does not move. According to Langmuir the following expression then holds:

$$b \ln \frac{b}{d} = k \frac{r}{s}, \quad (9)$$

where k represents a constant, while r is the viscosity and s the density of the gas. If, further, p is the pressure and m the molecular weight of the gas, then according to Fonda the following formula is found for the diffusion constant:

$$\gamma = \frac{Cte}{m d p \ln \frac{b}{d}}, \quad (10)$$

which we shall make use of in the following.

Comparison of the rates of evaporation in argon and krypton

According to (10) for two kinds of gas at the same

⁴⁾ H. A. Jones and I. Langmuir, Gen. El. Rev., 30, 310, 1927.

⁵⁾ E. Oosterhuis, loc. cit.

⁶⁾ G. R. Fonda, Phys. Rev., 31, 260, 1928.

⁷⁾ G. R. Fonda, Phys. Rev., 21, 343, 1923.

pressure the ratio of the diffusion constants γ' and γ'' is the following:

$$\gamma'' : \gamma' = \frac{\ln(b'/d) \cdot m'}{\ln(b''/d) \cdot m''} \cdot \cdot \cdot \quad (11)$$

From this the ratio of the diffusion constants γ of two rare gases, argon and krypton for instance, can be calculated.

The comparison between these two rare gases has become of real importance since the liquid gas industry has succeeded in obtaining krypton on a fairly large scale by a new process⁸⁾ which we shall not go into here. Krypton occurs in only extremely small quantities in the air, namely only one millionth by volume.

The molecular weights of argon and krypton are

$$m_{\text{Ar}} = 40 \text{ and } m_{\text{Kr}} = 83.$$

The viscosities at 20° C are

$$r_{\text{Ar}} = 2.21 \cdot 10^{-6} \text{ and } r_{\text{Kr}} = 2.48 \cdot 10^{-6}.$$

The densities of the gases are

$$s_{\text{Ar}} = 1.78 \text{ and } s_{\text{Kr}} = 3.71.$$

As diameter d of the filament let us choose that of the ordinary 40 Dlm lamp, while it may be remarked that the result of the calculation scarcely changes if one takes for d the diameter of the filament of a 150 Dlm lamp. Calculating b/d of equation (9) and filling this in (11) one obtains

$$\gamma_{\text{Kr}} = 0.59 \gamma_{\text{Ar}} \cdot \cdot \cdot \cdot \cdot \quad (12)$$

The diffusion constant γ for pure krypton thus amounts to about 60 per cent of that for pure argon. This figure has only a theoretical significance, however, since experience has shown that a filling of pure rare gas cannot be used in lamps for general service. The arcing voltage of rare gases is relatively low, so that in a lamp filled with a pure rare gas an arc may occur between the electrodes which renders the lamp useless. The chance of arcing in the rare gas is considerably diminished when nitrogen is added.

The choice of the proportion of nitrogen will in general be based upon a compromise. Much nitrogen means a decrease in efficiency, little nitrogen increases the chance of arcing.

The most satisfactory nitrogen content cannot therefore be determined on the basis of a limited number of laboratory tests. It is much better to rely upon the experience of many years and the extensive

statistical data furnished by the regular lamp testing on the basis of life tests.

In this way in the Philips concern experience has shown that with krypton a content of nitrogen at least 5 per cent higher than with argon must be added, if the same security against arcing of the gas is to be obtained. The arcing voltage of krypton is lower than that of argon.

In order not to make the discussion unnecessarily complicated we shall in the future, when argon and krypton are compared, calculate with the same percentage of nitrogen, namely a content of about 13 per cent which is customary for argon.

By the addition of nitrogen to rare gases the diffusion constant is affected. Fifteen years ago we investigated the rate of evaporation of tungsten wires in different mixtures of argon and nitrogen. It was then found that the rate of evaporation varies proportionally with the nitrogen content (see fig. 3, in which the rate of evaporation determined for krypton and pure xenon are also indicated). From this it follows that it is possible in general to calculate the diffusion constant γ of a gas mixture in a simple way from the ratio of the gases of which the mixture is composed.

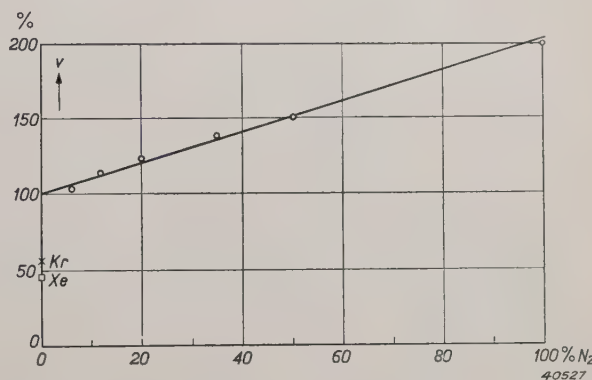


Fig. 3. Velocity of evaporation v in mixtures of argon and nitrogen as a function of the nitrogen content, expressed in % of the velocity of evaporation in pure argon. For the sake of comparison the velocities of evaporation in pure krypton $\times$ and xenon $\square$ are also indicated.

On this basis we have calculated the diffusion constants γ according to formula (10) for the ordinary lamps of 25, 40, 65, 100 and 150 Dlm with coiled-coil filament, not only of the series for 130 volts but also of that for 220—230 volts, and we have used the values found in equation (8). We then obtained the ratio of the values of E with a krypton or an argon filling. The E -values here considered are the ratios of the luminous flux in lumens to the energy radiated in watts. In order to be able to compare the results of our calculation with the results of practical measurements, where

⁸⁾ Ph. Siedler, *Angew. Chem.*, **51**, 799, 1938.

the ratio of the luminous flux to the power consumed, the so-called efficiency, is always determined, it is important to recalculate all results on this basis. We began at first with the assumption that the heat losses of the filament to the gas filling are the same for the krypton mixture as for the argon mixture. In *fig. 4* the results of the measure-

is assumed that the heat losses to the gas are the same for krypton as for argon.

The values obtained experimentally by both these methods are also included in *fig. 4*. The points indicated by small circles are obtained on the basis of light flux measurements, those indicated by crosses on the basis of determinations of the resist-

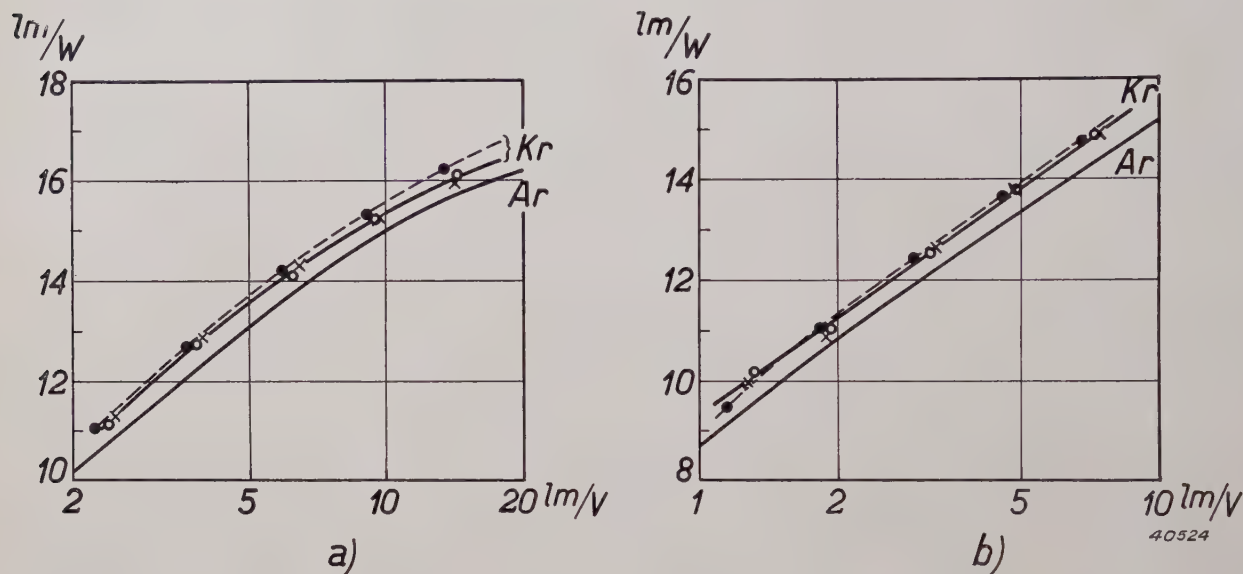


Fig. 4. The efficiency in lumens per watt is plotted as a function of the number of lumens per volt for a) lamps of 130 V and b) lamps of 220—230 V. The curves *Ar* are for argon filling and *Kr* for krypton filling, and the values calculated with formulae (10) and (8) are indicated by $\bullet$, while $\circ$ and $\times$ follow from measurements of the luminous flux and the resistance, respectively.

ments are shown, a) for lamps of low voltage and b) for lamps of high voltage. It may be concluded that for fillings of krypton and argon with the same percentage of nitrogen, the krypton will give an efficiency 4 per cent higher than that of argon, merely as a result of the difference in rate of evaporation for the same filament.

Investigation of coiled-coil lamps with different gas fillings

In order to test the theoretical results of the foregoing section about 50 of each of the 10 types of lamps mentioned were specially made with great care, one half filled with a krypton-nitrogen mixture and the other half with an argon-nitrogen mixture. After having been measured these lamps were subjected to a life test.

From the difference in luminous flux upon transition from argon to krypton the difference in temperature can immediately be calculated, and from that the change in efficiency. These latter figures can also be calculated from the difference in the resistance of the coil. All results are recalculated on the basis of the same life of 1000 hours, while it

ance of the incandescent filament. The two series of points show good agreement, not only with each other, but also with the points calculated according to formula (10). The theoretically found improvement of the efficiency upon transition from argon to krypton is about 4 per cent, while the experiments gave the result 3.2 per cent. The difference between these two results, while small, may perhaps be explained by the fact that the krypton-nitrogen mixture used already showed some tendency towards arcing and the formation of an arc, which makes the average life of the lamps shorter.

The value of about 4 per cent according to the calculation may therefore be considered as the maximum improvement, upon which one might count only if there were no danger of breakdown of the gas and if the heat losses to the gas were the same for krypton and argon. The somewhat lower value of 3 per cent found practically indicates that there is actually a danger of arcing. In order to eliminate this danger the nitrogen percentage of the krypton mixture should be chosen slightly higher, which would result in a decrease

in the improvement to be expected to about 3 per cent.

Thermodiffusion

Until now in our discussion we have taken into account only the ordinary diffusion of the evaporated tungsten through the gas. In addition to this there is the so-called "thermodiffusion"⁹⁾ which consists in the fact that in the presence of a temperature gradient in a gas mixture the heavier gas diffuses toward the colder zone. This diffusion is more rapid the steeper the temperature gradient and the greater the difference between the densities of the gases.

Since there is a very steep temperature gradient in the Langmuir film a considerable thermodiffusion of the heavy atoms of the vapourized tungsten may be expected; this diffusion will be more rapid in the lighter argon than in the heavier krypton. The rate of diffusion of tungsten in krypton should therefore be less than the 59 per cent of that in argon indicated by formula (13).

Since the rare gases used are not pure, but are mixed with nitrogen, the influence of the nitrogen on the thermodiffusion must still be ascertained. The latter gas in the mixture is also subject to thermodiffusion. As the lighter component it will diffuse toward the filament, so that there the gas mixture will be richer in nitrogen. Around the filament, therefore, the average density of the gas atmosphere is less than that of the gas mixture used for filling. The addition of nitrogen to the rare gas increases the diffusion and thus has an effect opposite to that which results from the transition from argon to krypton.

From the experiments it may be concluded that it is unnecessary to introduce a correction for the thermodiffusion into formula (10) since the experimental results do not lie above, but always below the results of the calculation.

Colour difference between argon and krypton lamps

From equation (5), since the ratio of the diffusion constants and the exponent g are known, the increase in temperature can be calculated upon the transition from the argon to the krypton mixture. For the ten types of lamps specially made for this investigation it amounts on an average to

$$\Delta T = 0.0125 T = 34^\circ \text{K (calculated).}$$

From the optical and electrical data we found for these types of lamps the increase in temperature given in *table I*.

Table I

ΔT , calculated from the increase in the light flux		ΔT , calculated from the increase of the resistance	
38 °K		45 °K	
14		24	
32		28	
28		32	
31		31	
29		24	
29		21	
28		20	
19		19	
15		21	
average	26.3 °K		26.5 °K

From this table it is evident that no systematic variation of ΔT with the luminous flux of the lamps investigated could be derived. The mean error is about 7° . The increase in the true temperature of a tungsten filament upon the transition from an argon to a krypton mixture as filling for the bulb, therefore, is an average of

$$\Delta T = 0.0098 T = 26^\circ \pm 7^\circ.$$

An investigation of krypton and argon lamps, as put on the market, with the help of the pyrometer gave a slightly lower average value for the difference, namely 20° , which may be explained by the somewhat higher nitrogen content in krypton lamps.

It need hardly be stated that it is impossible to perceive a temperature difference of 1% in electric lamps without optical instruments. This can easily be verified by a simple and yet technically convincing test. A krypton and an argon lamp are screened from each other and each used to illuminate part of a white surface. It is impossible to determine a colour difference with any degree of confidence.

Efficiency and heat losses

Since a considerable part of the energy which is taken by an electric lamp with gas filling is lost by direct heat conduction to the gas, we shall examine the influence of this on the efficiency somewhat more carefully. In the case of the 40 Dlm lamp for 220—230 volts, which is the most commonly used gas-filled lamp with single coil, almost 33 per cent of the energy was lost in this way, since it did not contribute to the light radiation. One of the means

⁹⁾ C. Ludwig, Wien. Ber., **20**, 539, 1856; Ch. Soret, Arch. Genève, **2**, 48, 1879; Ann. Chim. et Phys., **22**, 293, 1881; Chapman, Phil. Mag., **7**, 1, 1929; Ibbs, Proc. Roy. Soc., A **99**, 385, 1921.

of decreasing this loss and thus increasing the efficiency consists in using gases for filling, which have a poor heat conductivity.

According to Langmuir¹⁾ the heat W which a cylindrical filament gives off at the temperature T per cm length to the surrounding gaseous atmosphere with a temperature of 300 °K, is determined by the equation

$$W = \sigma (\varphi_T - \varphi_{300}), \dots (13)$$

where

$$\sigma = \frac{2\pi}{\ln\left(\frac{b}{d}\right)} \dots (14)$$

and
$$\varphi = 4.19 \cdot \int_0^T \lambda dT, \dots (15)$$

while b = the diameter of the Langmuir film,
 d = the diameter of the filament,
 λ = the heat conductivity of the gas.

The heat conductivity λ could be calculated with the help of Sutherland's formula for the viscosity and from the specific heat at constant volume. The constants occurring were taken from the Landolt-Börnstein tables.

The calculation of $(\varphi_T - \varphi_{300})$ for different temperatures T of the filament gave the values shown in *table II* for nitrogen, argon and krypton.

Table II

T	$\varphi_T - \varphi_{300}$		
	N ₂	Ar	Kr
1000 °K	0.293	0.216	0.124
1500	0.623	0.453	0.264
2000	1.030	0.743	0.438
2500	1.506	1.083	0.642
3000	2.047	1.451	0.868

When these values are represented in a graph with a double logarithmic scale (see *fig. 5*) they lie on a straight line for each gas, at least the values for 2000°, 2500° and 3000° K in which we are interested, so that we may represent $(\varphi_T - \varphi_{300})$ in this temperature region which is important for electric lamps by the formula:

$$\varphi_T - \varphi_{300} = \alpha_1 \cdot T^\beta \dots (16)$$

or also

$$\varphi_T - \varphi_{300} = \alpha \left(\frac{T}{2700}\right)^\beta, \dots (17)$$

where we assume that 2700 °K is approximately the average temperature of the tungsten filament.

The constants α and β then take on the values in *table III*.

Table III

	α	β
Nitrogen	1.70	1.65
Argon	1.22	1.65
Krypton	0.73	1.65

In order to calculate the losses by heat conduction by the gas, in addition to $(\varphi_T - \varphi_{300})$ the

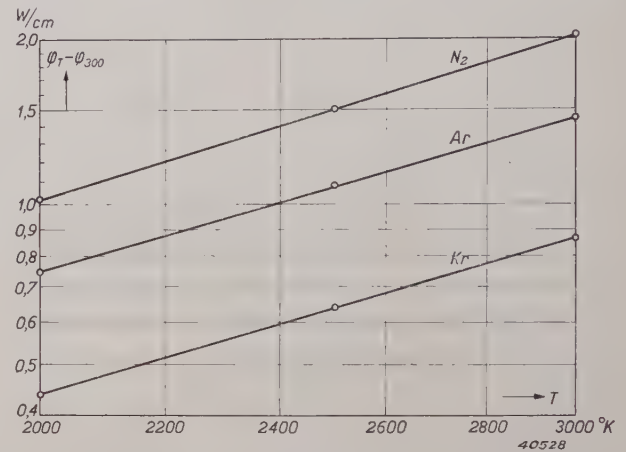


Fig. 5. The quantity $\varphi_T - \varphi_{300}$ in watts per cm as a function of the absolute temperature T for nitrogen, argon and krypton.

“shape factor” σ , which occurs in (13) must also be known. Langmuir gives the following formula for this:

$$\frac{d}{B} = \frac{\sigma}{\pi} \cdot e^{-2\pi/\sigma}, \dots (18)$$

where d again represents the diameter of the filament and B is the thickness of the Langmuir film for a plane surface. This formula corresponds to (9) with

$$k = \frac{s}{r} 2 B \dots (19)$$

For air with a pressure of 76 cm of mercury, according to Langmuir's measurements,

$$B = 0.43 \text{ cm.}$$

Langmuir has further assumed that B is proportional to the ratio of the viscosity and the density, so that from the known data B can be calculated for the different gases.

For a pressure of 57 cm one then finds that:

for nitrogen $B_N = 0.57 \text{ cm},$
for argon $B_{Ar} = 0.51 \text{ cm}$ and
for krypton $B_{Kr} = 0.27 \text{ cm}.$

From equation (18) it is now possible to calculate σ and thus also $W = \sigma (\varphi_T - \varphi_{300})$.

For $T = 2700\text{ }^{\circ}\text{K}$ one then obtains the heat losses given in *table IV* in W/cm for different diameters of the filament with rare gas mixtures containing 13 per cent of nitrogen.

Table IV

Diameter of the filament in μ	W/cm (2700 $^{\circ}\text{K}$, 57 cm of mercury)		
	N (pure)	Ar ₈₇ N ₁₃	Kr ₈₇ N ₁₃
100	3.08	2.37	1.78
200	3.62	2.80	2.12
300	4.01	2.11	2.38
400	4.35	3.38	2.61
500	4.66	3.62	2.82
700	5.18	4.03	3.20
1000	5.85	4.58	3.69

If the dimensions of the filament are known the energy lost by heat conduction can be calculated for the different gas mixtures, and on the basis of that, the way in which the efficiency is changed can be determined. This calculation was carried out for the ten specially made types of lamps; the results, for an argon mixture as well as for a krypton mixture are given in *fig. 6*.

It may be seen that when the argon mixture is replaced by a krypton mixture the efficiency in Dlm/W increases on an average of 3.6 per cent due to the smaller heat losses, when we assume that the rate of evaporation of tungsten is the same in argon as in krypton. This value will, however, fall

to 2-3 per cent, when, taking into account the greater chance of arcing in krypton, more nitrogen is added than is customary in the case of argon.

Final considerations

In this article we have studied successively the influence of the form of the filament and of the composition of the gas filling on the efficiency of lamps, the average life remaining the same. By passing over from single coil to coiled-coil filaments of the same luminous flux and life, an improvement of an average of 15 per cent in the efficiency was obtained. With this, however, the possibilities of development of the gas-filled lamp are by no means exhausted. Since the introduction of lamps with coiled-coil filaments a further improvement of the efficiency of this type has been obtained on the basis of earlier fundamental research¹⁰⁾, which, however, we shall not go into here.

According to the discussion given in this article it might be expected that by making use of krypton instead of argon for filling coiled-coil lamps a further improvement could be obtained as a result of the differences in rate of evaporation and in heat conduction. It must, however, be kept in mind that the improvement relates to the initial value of the efficiency. Since, however, during use this last quantity decreases more rapidly with krypton lamps than with argon lamps, in practice only a slight improvement will be obtained. Especially in large types of lamps this phenomenon occurs, be-

¹⁰⁾ E. Oosterhuis, loc. cit.

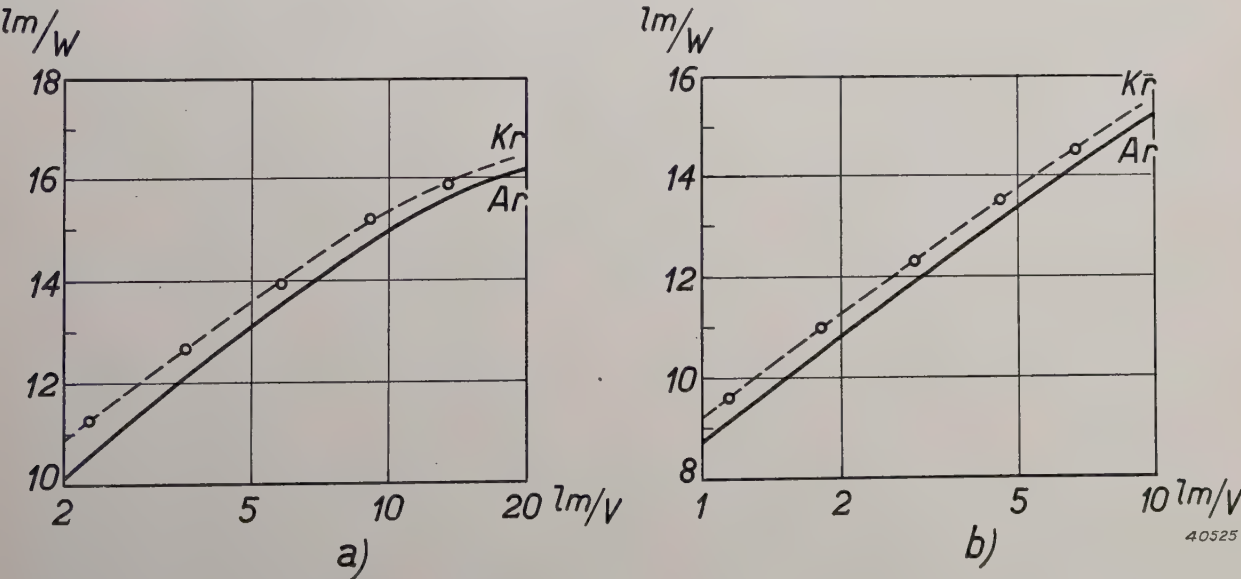


Fig. 6. The efficiency in lumens per watt which is obtained taking into account the different energy losses by heat conduction from the filament is plotted as a function of the number of lumens per volt. The curves are for argon (Ar) and krypton (Kr) mixed with 13% of nitrogen to prevent breakdown. a) is for lamps of 130 V and b) for lamps of 220—230 V.

cause due to the high cost of krypton relatively small bulbs must be used for krypton lamps, so that they become blacker than is the case with the corresponding argon lamps. In agreement with this we found that the lamps on the market with krypton filling and coiled coil, compared with our corresponding coiled-coil argon lamps of the same luminous flux, exhibited an improvement of 3 per cent in the efficiency throughout life. To what degree it is in general justifiable to realize this improvement, considering the cost of the krypton filling, is an economic problem which we shall not discuss here.

In general that development will be preferable

by which a technical advance can be attained without an intolerable increase in production costs, and with which, moreover, the new lamp can replace the existing type almost completely. A further requirement of the general utility of a new technical improvement is that it shall not have a retarding action on later possibilities of development. *The coiled-coil lamp filled with argon and in normal dimensions satisfies these conditions.* In recent years it has gained an absolutely dominating position with the result that the former lamp with single coil has practically become obsolete while it leaves the path open for further improvements in the future.

ON THE CONSTRUCTION OF VIBRATORS FOR RADIO SETS

by J. KUPERUS.

621.314.5 : 621.396.02

Several problems are discussed, which are connected with the construction of vibrators for the connection of an A.C. receiving set to the D.C. mains. The study of these problems has led to the development of a new type of vibrator which is described.

A description has already been given in this periodical of a vibrator which serves for the connection of A.C. receiving sets to a D.C. main¹⁾. In this article we shall discuss a number of problems connected with the construction of such vibrators and describe a new type of vibrator in which various improvements are incorporated.

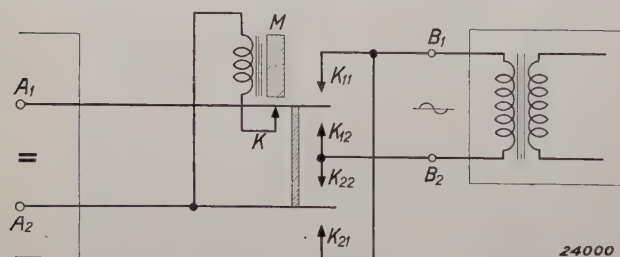


Fig. 1. Diagram of the connections of a vibrator.

The connections of a vibrator are represented diagrammatically in fig. 1. The springs A_1 and A_2 , which are insulated from each other electrically but joined mechanically, can alternately make contact against K_{11} and K_{12} , and K_{22} and K_{21} , respectively. The springs are moved by the electromagnet M acting on an armature which is mechanically con-

nected with the springs A_1 and A_2 . When these springs are in the stationary state the spring A_1 is connected with the coil of the magnet by means of the contact K . When the vibrator is connected to the D.C. mains the electromagnet will attract the armature and contact will be made between A_1 and B_1 and between A_2 and B_2 . At the same time the contact K is broken so that the armature is no longer attracted. Due to the effect of inertia the springs continue to move still farther and then swing back through the stationary state, making contact between A_1 and B_2 , and A_2 and B_1 , respectively. Due to the fact that the magnet is again excited each time in a suitable phase of the vibration of the springs, the mechanism keeps itself going. A current thus flows through the primary winding of the transformer which continually changes its direction, so that in the secondary winding an A.C. voltage is induced whose magnitude depends upon the voltage of the D.C. mains, among other factors, and on the ratio of the number of windings of primary and secondary coils of the transformer.

Due to the self-induction of the transformer and the magnet coil, with connections like those of fig. 1, a high voltage would occur between the points of

¹⁾ Philips techn. Rev., 2, 346, 1937.

contact each time a contact was broken. The sparks thus caused would considerably diminish the life of the contacts. Because of this the contacts are shunted with condensers.

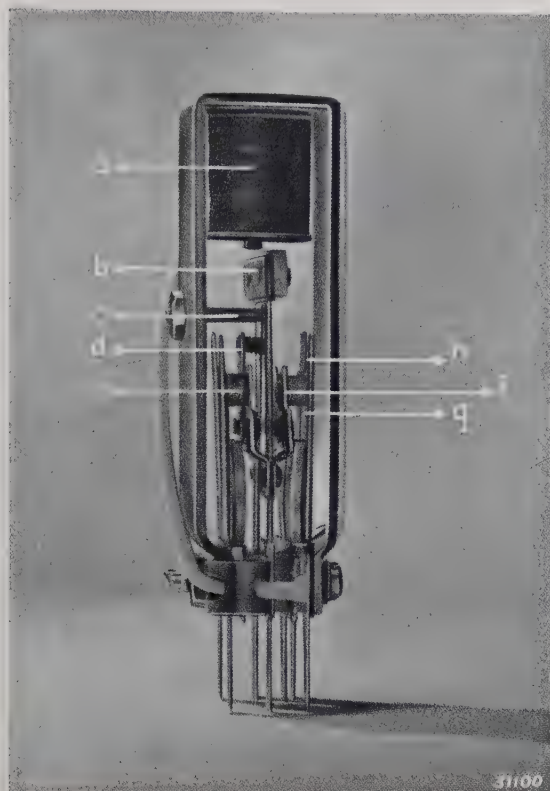


Fig. 2. New construction of the vibrator.

a = magnet coil,
b = armature,
c = stop for the spring *D* (see fig. 5),
d = contact for switching the current into the magnet coil,
e = contact for changing the direction of the current in the external circuit,
f, g and *h* may be compared with *1, 2* and *3* in fig. 7.

In order to prevent the penetration into the mains or into the receiving set of the high-frequency oscillations which occur due to the sudden current variations in the vibrator, the connection to the mains as well as to the receiving set is *via* filters. The complete vibrator thus consists of two parts, namely:

1. the vibrator proper
2. the coil and condensers for the filters and shunts across the contacts, built together as a compact unit. This part will be called the anti-interference part.

Both parts are housed together in an acoustically and electrically shielding container.

Fig. 2 shows a new construction of the vibrator. We shall now discuss several problems whose solution led to the construction illustrated in this figure.

The attachment of the vibrator to the anti-interference part

Since the vibrator contains moving parts, if it were rigidly fastened to the other parts the latter, including the container, would also be set vibrating. The result would be that sound vibrations would be transmitted to the surrounding air. In order to prevent this, the attachment of the vibrator to the anti-interference part is made in such a way that no vibration is transmitted to the anti-interference part upon vibration of the springs. In order to illustrate this method of fastening, the centres of gravity of certain parts of the vibrator are indicated in fig. 3*a*. *A* is the centre of gravity of the whole vibrator. Since with the method of fastening to be described no external forces act upon the vibrator due to the motion executed by the latter, the centre of gravity *A* will not change its position during this motion. *B* indicates the centre of gravity of the moving parts (armature and springs) while *C* represents the centre of gravity of the remainder of the vibrator. This remainder consists of the electromagnet with coil (centre of gravity *D*), the frame and the attachment of the springs (centre of gravity *E*). If *B* moves in a certain direction as a result of a deviation of the armature and the springs, then, since *A* remains stationary, *C* will move in the opposite direction. In fig. 3*b* this motion of the centres of gravity is represented. Since the part whose centre of gravity is formed by *B* does not execute a pure translation, but a movement which may in general be described as a translation

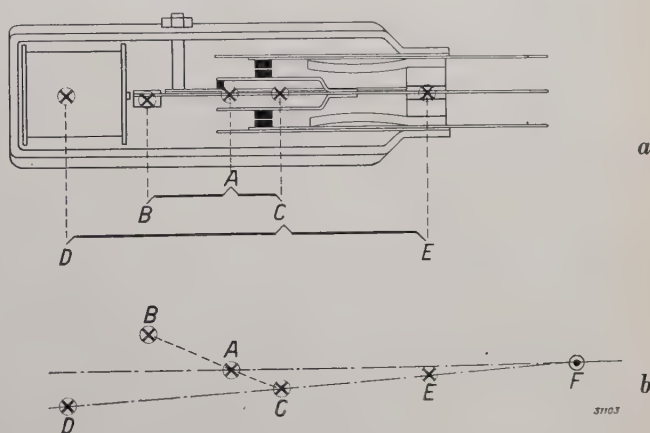


Fig. 3. *a*) Position of the centres of gravity of different parts of the vibrator.

b) Relative displacement of these centres of gravity.
A = centre of gravity of the whole,
B = centre of gravity of armature + springs;
C = centre of gravity of *D* + *E*; where
D = centre of gravity of electromagnet with coil,
E = centre of gravity of frame + attachment of springs,
F = point of attachment of the vibrator to the anti-interference part.

of the centre of gravity B and a rotation around the centre of gravity, the motion of the rest will also possess this general character, in which the rotation as well as the translation is in the opposite direction. This combined movement of the rest can be described as pure rotation around the point F in fig. 3*b*. This point therefore does not change its position in the movement executed by the vibrator. In the new construction of the vibrator the attachment of the vibrator to the anti-interference part takes place exclusively in the neighbourhood of point F , so that the motion of the vibrator can no longer be transmitted to the rest of the apparatus.

Since this fastening is flexible, upon fairly rough treatment in the transport of the vibrator it may easily be damaged. To prevent this the vibrator proper is so constructed that it can be fastened to the anti-interference part by means of a base which shows some similarity with a valve holder. The vibrator can therefore be taken out of the apparatus for transport and packed separately.

Improved construction of the contact for sending the current through the magnet coil

In older types of vibrators the contact K is always so constructed that the stop for the spring A_1 (see fig. 1) also serves as contact point. While this gives simplicity of construction, the objections involved in this system have, nevertheless, led to an alteration.

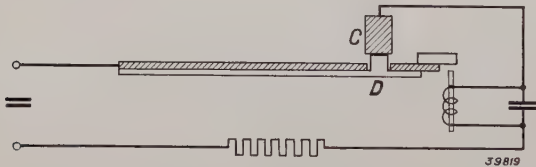


Fig. 4. Construction of the contact for sending the current through the magnet coil. The stop C of the spring D forms at the same time the contact.

In fig. 4 the older construction here referred to is shown diagrammatically. The fixed stop C thus serves at the same time as contact point, and together with D forms the contact K of fig. 1. A clear insight into the objection to this construction is obtained by a comparison with a hammer which strikes a heavy anvil. After the first contact with the anvil the hammer will rebound and again fall on the anvil, and the process will be repeated several times until the hammer comes to rest. The same thing occurs in a construction like that of fig. 4; before the contact between C and D is “definitely” made it is broken several times by the rebound of D . The result is that the current through the magnet

coil is interrupted a great many times more than is necessary, which has an unfavourable effect on the life of the contact.

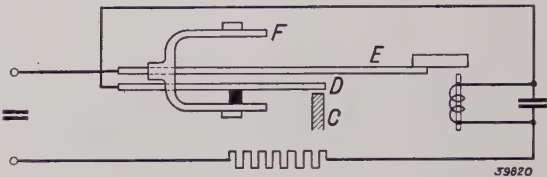


Fig. 5. The contact is made between D and F . This contact is closed at a moment when D does not rest upon C .

The principle of the improved construction is sketched in fig. 5. C is here again the stop for the spring D . Now, however, the spring D is not driven by the electromagnet but by the spring E to which the fork-shaped part F is fastened. The contact K is formed between this fork-shaped part and the spring D . The contact is closed when the spring E and thus also F moves upward, i.e. when D does not touch C . This construction may be compared with a hammer which strikes against an easily movable object; no rebound of the hammer takes place. The dying out of the vibration of the contact is thus prevented by this construction and a much longer life of the contact is obtained.

Improved construction of the contacts K_{11} - K_{22}

In the case of the contacts which serve for the continual alternation of the direction of the current also (fig. 1: K_{11} , K_{12} , K_{21} , K_{22}) the above-mentioned undesired damped vibration often occurs. The principle of the method by which this phenomenon has been combatted in these contacts is most clearly demonstrated by a comparison with billiard balls. If the ball 1 in fig. 6, moving in the direction of the arrow, strikes the stationary balls 2 and 3, 1 and 2 remain motionless or move only very slowly further, while 3 rolls on alone. The same thing happens with the springs of the vibrator. As indicated in fig. 7 behind the so-called side springs 2 are the extra springs 3. When 2 is struck by 1, 1 and 2 remain motionless, or move together over a short distance, and the contact between 1 and 2 is not broken. The spring 3 moves away from 2 but this causes no breaking of the contact.



Fig. 6. When ball 2 is truck by ball 1, 1 and 2 remain stationary, while 3 rolls away alone.

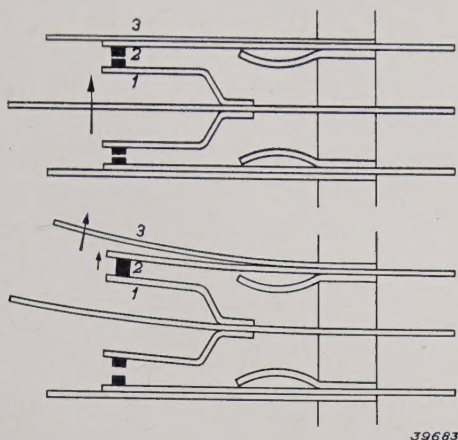


Fig. 7. By the action of the spring 3 the contact between 1 and 2, when once made, is prevented from being broken several times by the damped vibration. The distance between the contacts is exaggerated in this figure.

Limitation of the current

During ordinary use the vibrator takes up a current from the D.C. mains which is given by the load on the A.C. end. Under certain circumstances, however, this current may temporarily assume a much too high value. This may take place for example when a small particle of metal has fallen

between one of the contacts K_{11} - K_{22} . Since the distance between the contact surfaces in the open state is only 0.2 mm, a very small conducting particle is enough to cause one of the contacts to remain closed. The primary winding of the mains transformer of the radio set is then connected to the D.C. mains for too long a time and the current takes on too high a value. In order to prevent injury to the vibrator or the mains transformer, a fuse is included in the connection between the two. Since a defect of the nature described is generally of a temporary nature, the melting of this fuse is often not desired. For this reason a maximum relay is included in the vibrator which interrupts the connection with the contacts K_{11} - K_{22} upon the occurrence of too large a current impulse. The vibrator continues to function, but an unnecessary melting of the fuse has been prevented. Upon switching on the apparatus also a large current surge may occur, whereupon the maximum relay also goes into action.

Three coils are connected to the maximum relay, indicated by S_1 , S_2 and S_3 in fig. 8 in which the diagram of the complete vibrator is drawn (for

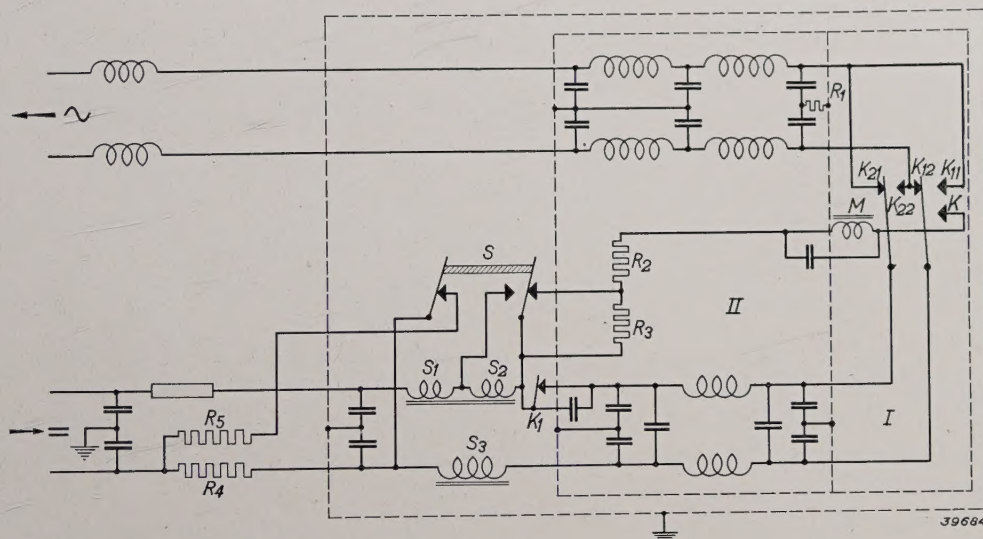


Fig. 8. Complete diagram of the connections of the vibrator. The vibrator proper and the anti-interference part are each placed in a separate shielded compartment, indicated by I and II, respectively. Outside of these are the maximum relay and an arrangement for switching over the vibrator for D.C. mains with different voltages. Around this whole the second shielding, already referred to, is placed. The vibrator can be connected to D.C. mains with a voltage of 220 volts as well as to those of 110 volts. For switching from 220 V to 110 V, three components must be changed:

- 1) A resistance in series with the magnet coil (R_2 , R_3). At the low mains voltage the resistance R_3 is short-circuited.
- 2) The maximum relay. Since the vibrator takes up a larger current at a lower mains voltage, the maximum relay must come into action at a higher current value. This is achieved by connecting the coil S_2 at the low mains voltage, which coil is wound in an opposite direction to S_1 .
- 3) The resistance which is connected in series with the vibrator. Upon use of a low mains voltage the resistance R_4 is connected in parallel with R_5 .

The commutation arrangement is indicated by the double switch S. Actually this is a contact block on the outside of the vibrator, which only needs to be reversed for switching over to the other mains voltage.

the significance of S_1 and S_2 see the text under the figure). When the current exceeds a certain maximum the contact K_1 is broken. This contact is also shunted by a condenser as may be seen in the diagram. In order to limit possible current surges a small resistance R_4 is connected in series with the whole. This resistance is situated in the connection of the vibrator leading to the radio set.

Complete shielding

It is always very difficult to house an apparatus in which the heat development is fairly high in an entirely closed shielding container. This is, however, very desirable for the vibrator, in connection with the great interference which it may otherwise cause in the radio reception. We have succeeded in keeping the energy loss which occurs in the vibrator

so low that the apparatus could be placed in a completely closed container, thus even without ventilation holes. In order to obtain the greatest possible security from interference the shielding is double. The energy loss was kept small, and thus the heat development also, by making the moving parts (springs and armature) as small as possible. By this means a small current, namely only 20 mA, in the coil of the electromagnet M is sufficient to keep the vibrator in motion.

Keeping the energy loss small is of course also an advantage from the point of view of efficiency. In the case of this vibrator the efficiency amounts to about 90 per cent.

Finally in *fig. 9* the complete vibrator is shown. The double shielding of the vibrator proper has here been removed in order to show the main parts more clearly.

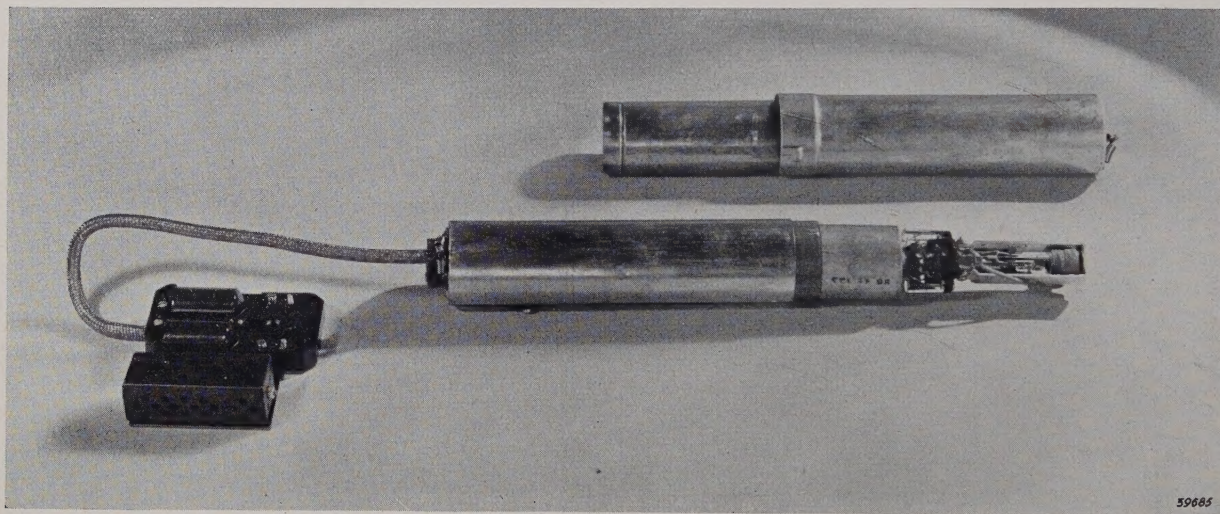


Fig. 9. The complete vibrator. Left, anti-interference part, right vibrator. Behind, slid partially into one another, are two cans with which the vibrator is doubly shielded.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.

- 1545:** J. L. Snoek: The influence of eddy currents on the apparent hysteresis loop of ferromagnetic bars (*Physica* **8**, 426-438, Apr. 1941).

In this article a commonly neglected error in measurement is discussed which occurs in ferromagnetic measurements on bars or wires of magnetically soft material. In this case the external magnetic field is practically completely compensated by the demagnetizing field. If the external field is now changed so rapidly that the field in the interior of the bar can only follow with a large time lag due to eddy currents, the demagnetizing factor is temporarily very much reduced. This results in the fact that the interior of the rod is much too strongly magnetized for a short time. When the final state is once reached the inner part of the bar is thus on the descending branch of the magnetization curve instead of on the mounting branch. The area of the hysteresis curve thus appears smaller than it actually is. The coercive force measured is also too small. These errors in measurement occur when the time constant of the external field is small compared with the time constant of the material. The magnitude of the error in the change in induction observed also depends upon the ratio of the field change to the accompanying change in the demagnetization field. The error therefore does not occur in ring-shaped test pieces which have no poles. The shape and the magnetic properties of the material further determine the maximum error which can occur. With materials with not too small a coercive force the occurrence of this error need not be feared very much, since in this case the time constant of the external field will usually be much larger than that of the material.

- 1546:** M. J. Druyvesteyn: The elastic anisotropy of molybdenum (*Physica* **8**, 439-448, Apr. 1941). (Original in German).

The modulus of elasticity and the modulus of torsion are determined for polycrystalline molybdenum and for strips which have been cut with a chisel in different directions out of rolled plates of molybdenum, which clearly show a texture. The different elastic constants of molybdenum can now

be calculated from these measurements and the compressibility determined by Bridgman. Molybdenum is the first metal for which it has been determined that the modulus of elasticity in the direction of the main diagonal is smaller than that along the edges of the elementary cube of the crystal.

- 1547*:** W. G. Burgers: Recrystallization, deformed state and recovery (553 pp; Akad. Verlagsgesellschaft, Becker und Erler Kom. Ges., Leipzig 1941) (In German).

This book is published as volume III, part II of the *Handbuch der Metallphysik* and offered the writer the opportunity of presenting his extensive knowledge of the subject of recrystallization in a comprehensive way. After an introduction in which, among other features, a nomenclature for the different phenomena of recrystallization is given and the methods of investigating them are dealt with, follow chapters on recrystallization in unworked substances, on the cold-worked state and its recrystallization. Furthermore the recrystallization temperature and the duration of recrystallization are discussed, as well as the influence of impurities and alloy components on the recrystallization of purer metals. In conclusion the significance is discussed of recrystallization on stiffening and plasticity.

- 1548:** M. J. O. Strutt: Spontane spannings- en stroomfluctuaties (ruischen) in elektronenbuizen en aangeloten ketens (Spontaneous voltage and current fluctuations (noise) in electronic valves and circuits connected with them) (*T. Ned. Rad. Genoot.* **9**, 1-36, June 1941).

In this lecture given before the Netherlands Radio Society (Nov. 1940) a survey was given of the noise phenomena which have in general already been dealt with in detail in the different articles devoted to "noise" in Philips techn. Rev. Equivalent circuit diagrams and a short derivation are given which constitute a considerable simplification in the treatment of noise phenomena.

- 1549:** B. D. H. Tellegen: Meetkundige configuraties en dualiteit van elektrische netwerken (Geometrical configurations and duality

of electrical networks) (T. Ned. Rad. Genootschap **8**, 37-60, June 1941).

This lecture given before the Netherlands Radio Society (Nov. 1940) is an elaboration of the article contributed by the author to Philips techn. Rev., **5**, 324, 1940. He took the opportunity of going somewhat more deeply into the proofs of the theorems dealt with and of illustrating them by means of a few examples.

1550: F. A. Heyn: Het opwekken van mutaties door straling (The excitation of mutations by radiation). (Vakbl. Biol. **22**, 81-88 and 101-105, May and June 1941).

The mutation-causing effect of different kinds of radiation is investigated as a function of the dosage and other external conditions. It is found that there is no question of a specific action of certain kinds of radiation, but that mutations occur when sufficient energy is transferred to a certain sensitive part of a gene. It is not possible to excite definite desired mutations in this way, but there is a good chance of encountering useful mutations among the many less vigorous ones which are obtained with a sufficiently intense radiation, so that in addition to theoretical significance for the general study of heredity, this method will also certainly have practical significance for the improvement of plants and animals.

1551: J. van Niekerk: On the influence of emanation on the development of experimental rickets in young rats (Act. brev. Neerl. **11**, 142-147, 1941).

The large fluctuations which occur in the development of artificially produced rickets in large numbers of rats, which are needed for instance for the standardization of vitamin D preparations, are ascribed by various investigators to the variability of different external factors. Even though great care is taken to secure constancy of the rachitogenic diet fed to the rats, the large fluctuations in the development of the rickets continue to occur. Dols and Jansen ascribed this to variations in the content of radium emanation in the air with the season of the year. By keeping different rats under otherwise similar conditions in cages with different contents of radium emanation the author has shown that this content has no effect on the development of experimental rickets in rats.

1552: G. W. Rathenau and J. L. Snoek: Magnetic anisotropy phenomena in cold-rolled nickel-iron (Physica **8**, 555-575, June 1941).

The strong magnetic anisotropy observed in cold-rolled nickel-iron alloys can neither be explained as due to internal stresses nor as due to the natural anisotropy of the crystals. A geometric tetragonality of these alloys which was indicated by G. Wassermann as the cause, cannot fully explain the phenomenon. The influence of the composition of the alloy and of the treatment which it has undergone on the anisotropy of its mechanical properties was further investigated. In this investigation it is particularly remarkable that the natural crystal anisotropy and the magnetostriction are not appreciably affected by the rolling. The investigations suggest a relation between the anisotropy phenomena and the familiar phenomenon of order in the nickel-iron system. The authors, however, do not consider it very probable that the anisotropy phenomena are a direct result of the tendency toward order.

1553: M. J. O. Strutt and A. van der Ziel: Decrease and elimination of the spontaneous fluctuations in the amplification of extremely small photocurrents (Physica **8**, 576-590, June 1941) (Original in German).

In continuation of **1529** the authors discuss the amplification of extremely small photocurrents in connection with the fluctuations occurring in the amplifier. These fluctuations can be limited by using only a narrow frequency band preceding the first amplifier stage, and extending it in the following stages, or by making use of an electron multiplier. A new method of limiting the fluctuations is indicated in which a special method of backcoupling is applied. The ratio of signal to noise is calculated and compared with that in the previous cases. In conclusion the extent is examined to which this new method for limiting the noise can also be profitably employed in other cases.

Contents of Philips Transmitting News **3**, No. 2, June 1941.

M. v. d. Beek, Attenuation and impedance of dipole aeriels.

C. A. Gehrels, A crystal-controlled testing installation for transmitting valves for 100 kW carrier-wave power on a wavelength of 15 metres.

Th. Douma, Resonance of circuits and lines II.